MEMORANDUM REPORT ARBRL-MR-03359

THRUST CHARACTERIZATION OF VERY HIGH BURNING RATE PROPELLANTS

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT CENTER
BALLISTIC RESEARCH LABORATORY
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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A series of closed bomb combustion tests were conducted on several very high burning rate (VHBR) propellants in which, in addition to the standard pressure measurements, the thrust produced by a burning propellant column was measured using a dynamic force gage located at the end of the propellant column. The results indicate that in several instances the total force imparted to the force gage substantially exceeded that due to the gas pressure alone. The difference is ascribed to the thrust or impulse resulting from very high

1. INTRODUCTION

Our research on the combustion characterization of very high burning rate (VHBR) propellants is motivated by the need for such propellants for the successful exploitation of the traveling charge gun propulsion concept proposed initially by Langweiler.[1] The traveling charge concept remains perhaps the only propellant approach to overcome the severe intrinsic ballistic inefficiency of conventional chemical gun propulsion if muzzle velocities greater than 2 km/s are to be attained. In a traveling charge configuration, a projectile is accelerated by a combination of gas pressure and impulse produced by a fast burning propellant attached to and moving with the projectile. A discussion of previous work and the basic concept has been given by May et al.[2] Combustion diagnostics in a standard closed bomb configuration for a family of VHBR propellants have been described by Juhasz et al.[3] These observations can be summarized as follows: apparent very high burning rates appear to be density-, confinement-, and formulations-dependent. The extracted apparent burning rates are, therefore, not true intrinsic linear burning rates explainable by conventional combustion models. A mechanism such as convection burning[4] or progressive stress-induced surface breakup[5] is thought to be the process responsible for very high apparent burning rates. Because such burning rates result in the production of substantial amounts of thrust, we have developed a modified closed bomb described below in which the total force produced by the combined gas pressure and thrust transmitted through a column of VHBR propellant is measured. Experimental observation of thrust can then be used to extract apparent burning rates in a direct manner. Such burning rates should be more reliable for interior ballistic modeling than those obtained by standard closed bomb techniques as previously described.[3]

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[1] *H. Langweiler, "A Proposal for Increasing the Performance of Weapons by the Correct Burning of Propellant," British Intelligence Objective Sub-Committee, Group 2, Fort Halstead Exploiting Center, No. 1247.*

[2] *I. W. May, A. F. Baran, P. G. Baer, and P. S. Gough, "The Traveling Charge Effect," Ballistic Research Laboratory Memorandum Report ARBRL-MR-03034, July 1980 (AD B052135L).*

[3] *A. A. Juhasz, I. W. May, F. R. Lynn, R. E. Bowman, W. P. Aungst, "Combustion Diagnostics of Very High Burning Rate Propellants," 17th JANNAF Combustion Meeting, CPIA Publication 329, pp 209-240, November 1980.*

[4] *R. A. Fifer and J. E. Cole, "Transitions from Laminar Burning for Porous Crystalline Explosives," Seventh Symposium (International) on Detonation, Naval Surface Weapons Center, MP 82-334, June 1981.*

[5] *D. E. Kooker and R. D. Anderson, "A Mechanism for the Burning Rate of High-Density, Porous, Energetic Materials," Seventh Symposium (International) on Detonation, Naval Surface Weapons Center, MP 82-334, June 1981.*

2. EXPERIMENTAL DETAILS

2.1 PROPELLANTS

In this study, a series of propellant formulations based on salts of the decahydrodecate anion as the important fuel ingredient were used.[6] Results for only three VHBR propellants listed in Table 1 are presented in this paper. Their computed thermochemical performance parameters are given in Table 2.

TABLE 1. VHBR PROPELLANT FORMULATIONS

Sample Code	Fuel	%	Oxidizer	%	Binder	%	Density (% TMD)
1086-3	466	25.7	AN	59.1	NC/DNT	15.2	91
1086-5A	498	8.8	TAGN	76.0	NC/DNT	15.2	98
1086-6B	466	27.0	AN	67.1	C4000	5.0	88

TABLE 2. VHBR THERMOCHEMICAL PROPERTIES

Sample Code	Impetus (J/g)	Flame Temperature	Covolume (cm^3/g)	Specific Heat Ratio
1086-3	985	2538	1.095	1.1974
1086-5A	1055	2647	1.220	1.2500
1086-6B	983	2488	1.089	1.1916

The fuel ingredients used are proprietary to Teledyne-McCormick/Selph.* Triaminoguanidinium nitrate (TAGN) and ammonium nitrate (AN) are the oxidizers. Nitrocellulose (NC), dinitrotoluene (DNT), and carbowax (C4000), a polyethylene glycol with an approximate molecular weight of 4000, are the binders. All samples were pressed to right circular cylinders 51-mm long with a diameter of 12.7 mm.

2.2. THRUST TEST FIXTURE

The thrust bomb experiments were conducted at Calspan Corporation, Buffalo, NY.** The device is depicted in Figure 1. It is a 419-mm-long closed bomb with an internal diameter of 12.7mm. The propellant sample is mounted against one end of the chamber, which consists of a 934-mm-long steel rod. Strain gages are located on this stress bar 40.2 mm from the chamber propellant/bomb interface. Pressure transducers (PCB 118A) P1, P2, P3, and P4, are located 4.8, 27.0, 55.6, and 219.4 mm respectively in the chamber from the same interface. Gage P3 is located near the initial propellant/chamber interface. Data from this gage were used in the subsequent analysis. Gages

* Contract DAAK11-77-C-0035
** Contract DAAK11-80-C-0062

[6] *C. S. Leveritt, "Ultra High Burning Rate Propellants for Traveling Charge Gun," Ballistic Research Laboratory Contractor Report, ARBRL-CR-00447, Feb, 1981.*

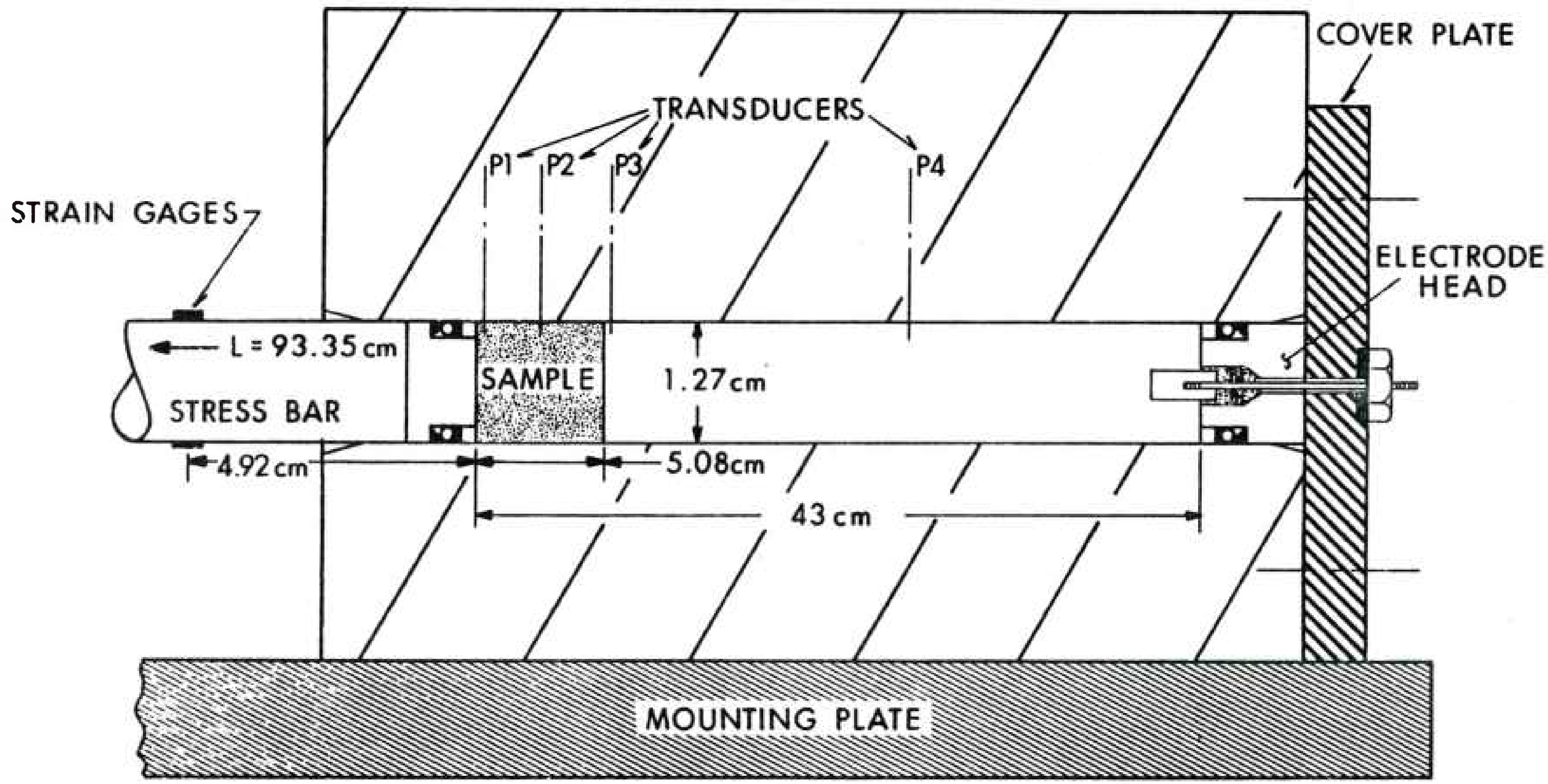

Figure 1. Thrust Bomb Fixture

P2 and P1 are difficult to use for the analysis because they respond to solid stress. They are flush-mounted and are in virtual contact with the propellant. The long rod allows dynamic stress measurements to be made unperturbed by rod-end reflections for a period of about 350 microseconds. The propellant is ignited cigarette-fashion with an electric match boosted with 1 g of FFFG black powder. The stress in the rod is due to the combined gas pressure and impulse transmitted through the propellant column as the VHBR material burns.

2.3 DATA ACQUISITION

The data for the experiments were acquired on three NICOLET Explorer III digital memory oscilloscopes. Where necessary, the digital data were filtered using Fast Fourier Analysis techniques. Small, but important, uncertainties in timing among the oscilloscopes required some time-biasing to achieve an internally consistent sequence of events. The method of biasing employed was overlaying and matching the P3 and the rod stress (RS) in the initial slow pressurization region where steady state conditions should prevail. Adjustments of this sort up to 24 microseconds were made in the same runs.

2.4 ANALYSIS

The effectiveness of the traveling charge concept depends directly on the production of substantial amounts of impulse as thrust. The direct observation of thrust, although critical from a practical standpoint, allows the extraction of effective burning rates. From a combustion characterization standpoint, this is of great significance. To determine the rate of surface regression of the propellant grain, we assume the flame to be sufficiently thin as to be quasi-steady. Then the equations[7] describing the conservation of mass, momentum, and energy for the propellant transported across the surface discontinuity are in consistent units,

$$\rho_g \cdot (u_g - \dot{X}_p) = -\rho_p \cdot r \tag{1}$$

$$P + \frac{\rho_g}{g_o} (u_g - \dot{X}_p)^2 = \sigma + \frac{\rho_p}{g_o} \cdot r^2 \tag{2}$$

$$e + \frac{P}{\rho_g} + \frac{1}{2g_o} (u_g - \dot{X}_p)^2 = e_p + \frac{\sigma}{\rho_p} + \frac{r^2}{2g_o} \tag{3}$$

where

$$\dot{X}_p = u_p + r \tag{4}$$
is the velocity of the gas/propellant interface

$$e = \frac{P(1-b\rho_g)}{(\gamma - 1)\,\rho_g} \tag{5}$$
is the internal energy of the gas

[7] P. S. Gough, "A Model of the Traveling Charge," Ballistic Research Laboratory Contractor Report, ARBRL-CR-00432, July 1980.

ρ_g, ρ_p are the gas and propellant densities

u_g, u_p are the gas and propellant velocities

r is regression rate of grain surface

P is gas pressure at interface

g_o is gravitational constant

σ is propellant stress at interface (positive in compression)

e_p is energy of propellant

b is covolume of propellant

γ is ratio of specific heats of propellant

Combination and simplification of these three equations yields:

$$r^2 = \frac{g_o}{2\rho_p^{\,2}} \cdot \frac{(\sigma - P) \cdot (\sigma + \frac{\gamma + 1}{\gamma - 1} \cdot P)}{e_p + \frac{P}{\gamma - 1} \cdot (b - \frac{1}{\rho_p})} \tag{6}$$

In order to determine σ and P at the reaction front, the experiment is idealized as in Figure 2. Density is denoted by ρ, and c is the sound speed in each medium. The mechanical response of both the propellant grain and the steel bar - taken to be semi-infinite - was assumed to be linear-elastic and one-dimensional. Then, employing the characteristic form of the equations of motion and applying the appropriate boundary conditions, we have the stress at the reaction front, $\sigma^o(-\ell, t)$, and velocity, $u_p^o(-\ell, t)$, in terms of the measured stresses, $\sigma(\ell_1, t_i)$,

$$\sigma^o(-\ell, t) = \frac{\rho_p c_p}{2\rho_s c_s} \cdot \{\sigma(\ell_1, t_1) - \sigma(\ell_1, t_2)\} + \frac{1}{2} \cdot \{\sigma(\ell_1, t_1) + \sigma(\ell_1, t_2)\} \tag{7}$$

$$u_p^o(-\ell, t) = \frac{g_o}{2\rho_s c_s} \cdot \{\sigma(\ell_1, t_1) + \sigma(\ell_1, t_2)\} + \frac{g_o}{2\rho_p c_p} \cdot \{\sigma(\ell_1, t_1) - \sigma(\ell_1, t_2)\} \tag{8}$$

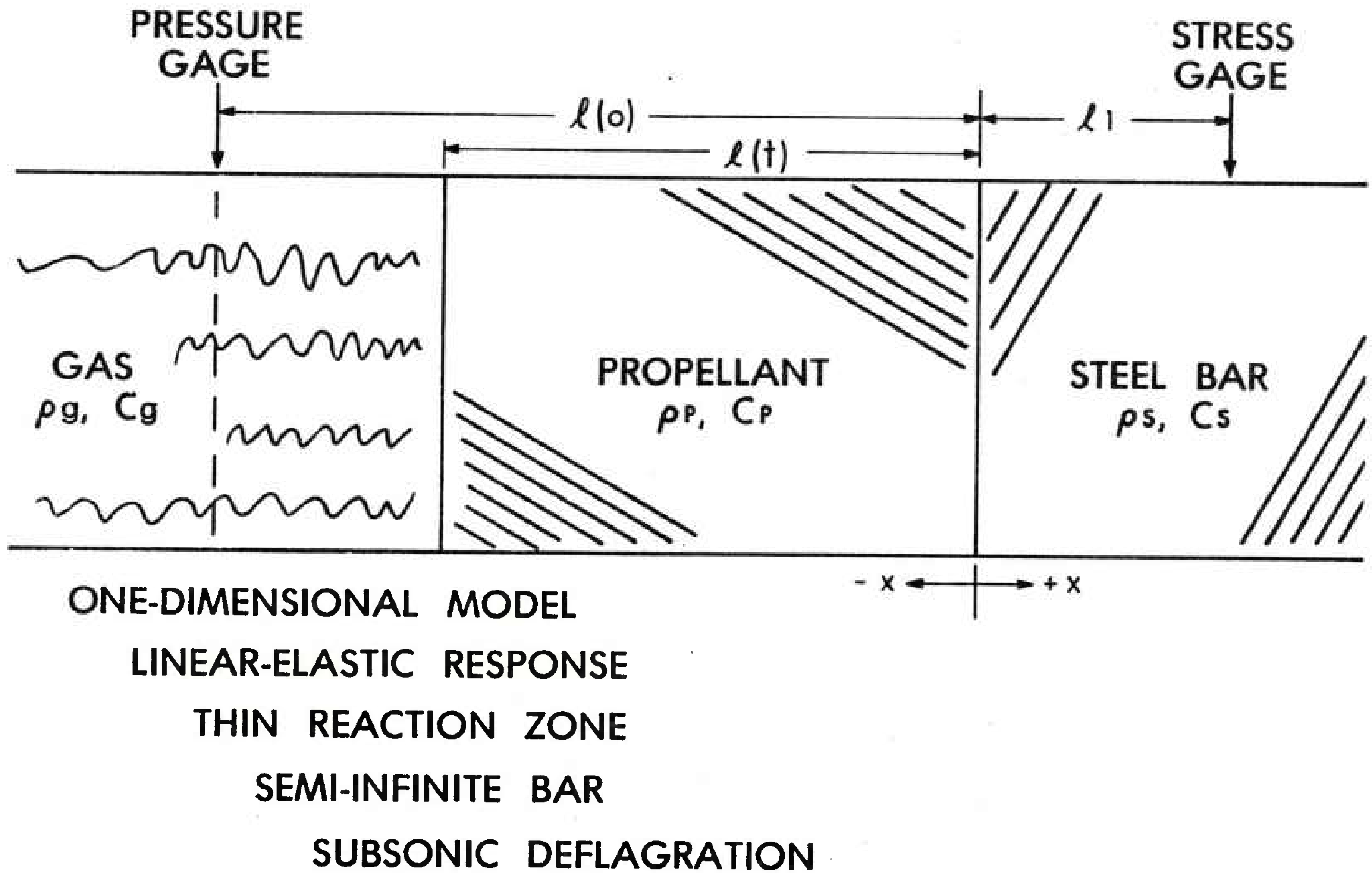

Figure 2. Model Used in Analysis

where

$$t_1 = t + \frac{\ell(t)}{c_p} + \frac{\ell_1}{c_s} \tag{9}$$

$$t_2 = t - \frac{\ell(t)}{c_p} + \frac{\ell_1}{c_s}\ . \tag{10}$$

Incorporation of a simplified representation for wall friction, f_w, taken to be acting on the grain as a whole gives the friction-corrected stress and velocity

$$\sigma(-\ell,t) = \sigma^o(-\ell,t) + \frac{c_p}{2g_o} \cdot \left\{ f_{w1} \cdot \Delta t_1 + f_{w2} \cdot \Delta t_2 \right\} \tag{11}$$

$$u_p(-\ell,t) = u_p^o\ (-\ell,t) + \frac{1}{2\rho_p} \cdot \left\{ f_{w1} \cdot \Delta t_1 - f_{w2} \cdot \Delta t_2 \right\} \tag{12}$$

where

$$f_{w1} = \frac{\mu}{R} \cdot \left\{ \sigma(-\ell,t) + \sigma(\ell_1,t_1) \right\} \tag{13}$$

$$f_{w2} = \frac{\mu}{R} \cdot \left\{ \sigma(-\ell,t) + \sigma(\ell_1,t_2) \right\} \tag{14}$$

$$\Delta t_1 = t_1 - t \tag{15}$$

$$\Delta t_2 = t - t_2 \tag{16}$$

μ = coefficient of friction

R = radius of sample

The method of characteristics is also invoked to extract the pressure at the reaction front, $P(-\ell,t)$, from gage pressures measured at a position coincident with the initial grain surface, $P_m(-\ell(0),t)$, assuming no discontinuities in the gas column, i.e., subsonic flow throughout, and a lack of pressure waves reflected from the empty end of the chamber. This analysis yields

$$P(-\ell,t) = 2 \cdot P_m(-\ell(0),t_3) - P(-\ell,t_4)$$

$$+ \frac{\rho_g(t_3) \cdot c_g(t_3)}{g_o} \cdot \left\{ u_g(t_4) - u_g(t) \right\} \tag{17}$$

where

$$t_3 = t - \frac{\ell(0) - \ell(t)}{u_g(t_3) + c_g(t_3)} \tag{18}$$

$$t_4 = t_3 - \frac{\ell(t_4) - \ell(0)}{u_g(t_3) - c_g(t_3)} . \tag{19}$$

The original conservation equations imply that, at any time $T > 0$, the gas velocity is

$$u_g(T) = u_p(T) - \frac{g_o}{\rho_p(T)} \cdot \frac{\sigma(-\ell,T) - P(-\ell,T)}{r(T)} \tag{20}$$

and the gas density is

$$\rho_g(T) = \frac{-\rho_p(T) \cdot r\,(T)}{u_g(T) - u_p(T) - r(T)} . \tag{21}$$

The propellant density is taken to be

$$\rho_p(T) = \rho_p(0) + \frac{g_o \cdot \sigma(-\ell,T)}{c_p^2} \tag{22}$$

and the covolume equation of state gives the gas sound speed

$$c_g^{\,2}(T) = \frac{\gamma \cdot P(-\ell,T) \cdot g_o}{\rho_g(T)} \cdot \frac{1}{1 - b \cdot \rho_g(T)} . \tag{23}$$

By suitable iteration until convergence, the stress, $\sigma(-\ell(t),t)$, and pressure, $P(-\ell(t),t)$, at the reaction front are thus calculated, producing the desired regression rate, $r(t)$, and the net thrust on the propellant grain, $\sigma - P$. A computer program written in BASIC to reduce the experimental data according to the above method is listed in APPENDIX A.

3. RESULTS AND DISCUSSION

Three separate tests are reported. In the first test, results for a very fast burning propellant are presented. The second case shows results for an intermediate burning rate propellant. The last case is an anomalous case, for which no thrust production was observed.

3.1. FAST BURNING CASE

A propellant sample of composition 1086-5A at a TMD of 98% resulted in the most dramatic demonstration of a substantial thrust contribution due to very high burning rates. The printed output from a computer reduction of the data from this experiment is listed in APPENDIX B, and plotted in Figures 3 through 5. Figure 3 shows derived pressure and stress at the gas-propellant interface as a function of time. The data look quite similar to the measured values of P3 and rod strain but offset in time. The maximum value of stress to pressure (σ/P) max is greater than two. The force produced by thrust alone, therefore, exceeded the force produced by the gas pressure!

Regression rates up to 300 m/s were computed for this case. Considering the different assumptions in the two analysis methods, our value matches the high burning rate value from the standard closed bomb analysis[3] remarkably well. The computed regression rate, as a function of pressure, is plotted in Figure 4. Contrary to the previous[3] analysis results, however, Figure 4 shows a clear regression-rate dependence on pressure, the burning rate rising and falling as the pressure rises and falls. The rise and decay times of this event are on the order of 100 microseconds. In this highly transient environment it is, perhaps, not surprising that the regression rates are not the same in both the pressurization and the depressurization region. A more thought-provoking result is shown in Figure 5, which correlates regression rate and stress. With such a strong correlation, it is natural to conjecture that a solid-phase stress-induced mechanism such as surface breakup is a strong factor in the burning mechanism.

In the analysis of the data, a constant value of longitudinal sound speed equal to 2 km/s was assumed for the propellant. This value is similar to an experimentally determined value for a comparable propellant formulation reported by Finger.[8] A small parametric study of the effect of propellant sound speed shows interesting results. Reducing the sound speed to 1.8 km/s improves the correlation of apparent burning rate versus stress in the initial portion of the curve as shown in Figure 6. Increasing the sound speed to 2.5 km/s significantly improves the correlation at the upper end of the curves of both stress and pressure. The stress vs apparent burning rate for this case is shown in Figure 7. It is tempting to suppose that the sound speed should increase with compaction as the density increases, but it is essential that independent measurements of sound speed as a function of imposed stress be made.

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[8] M. Finger, "Hivelite Propellant Characterization," Lawrence Livermore Laboratory Report, UCID-16478, March 1975.

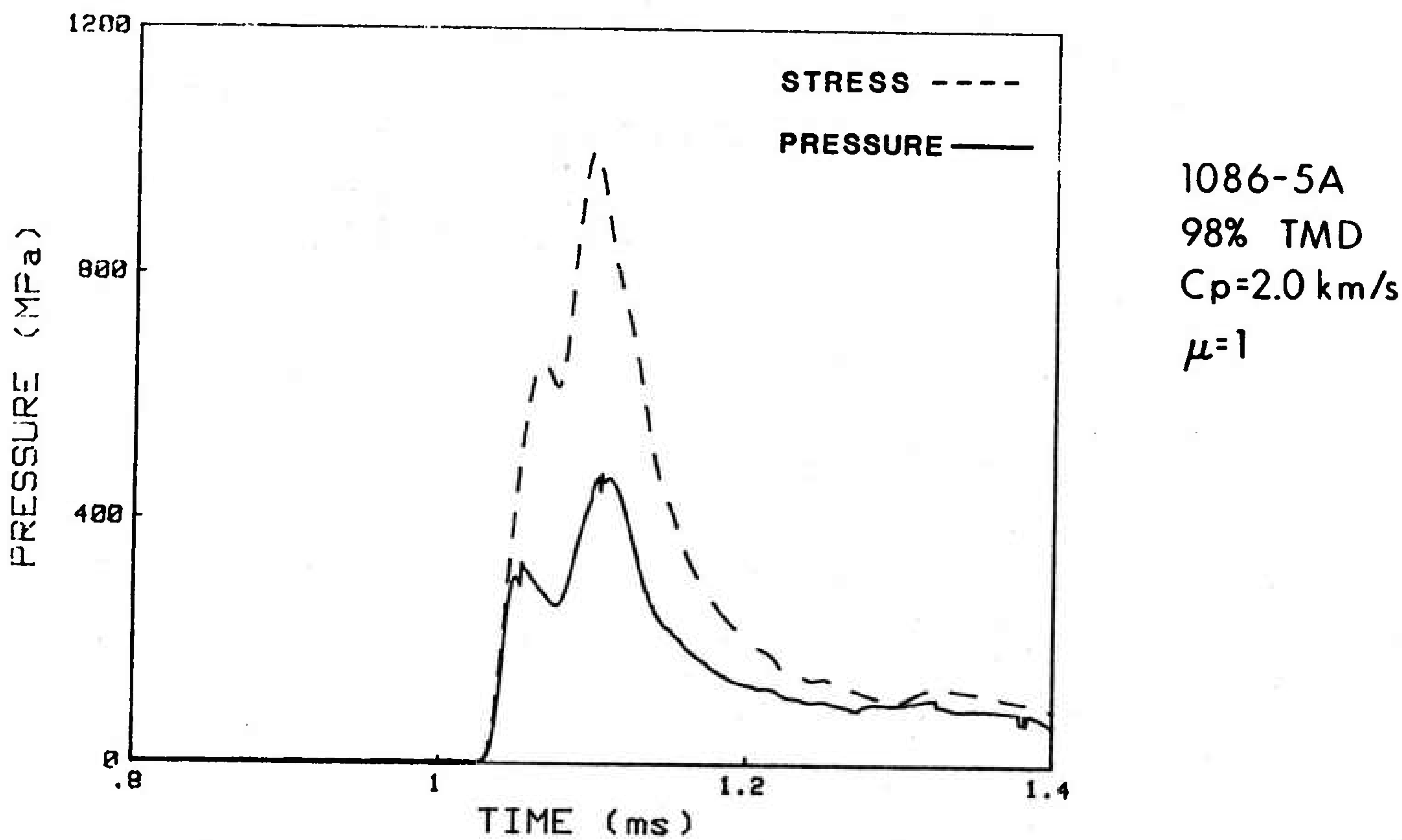

Figure 3. 1086-5A: Interface Pressure (-) and Stress (---)

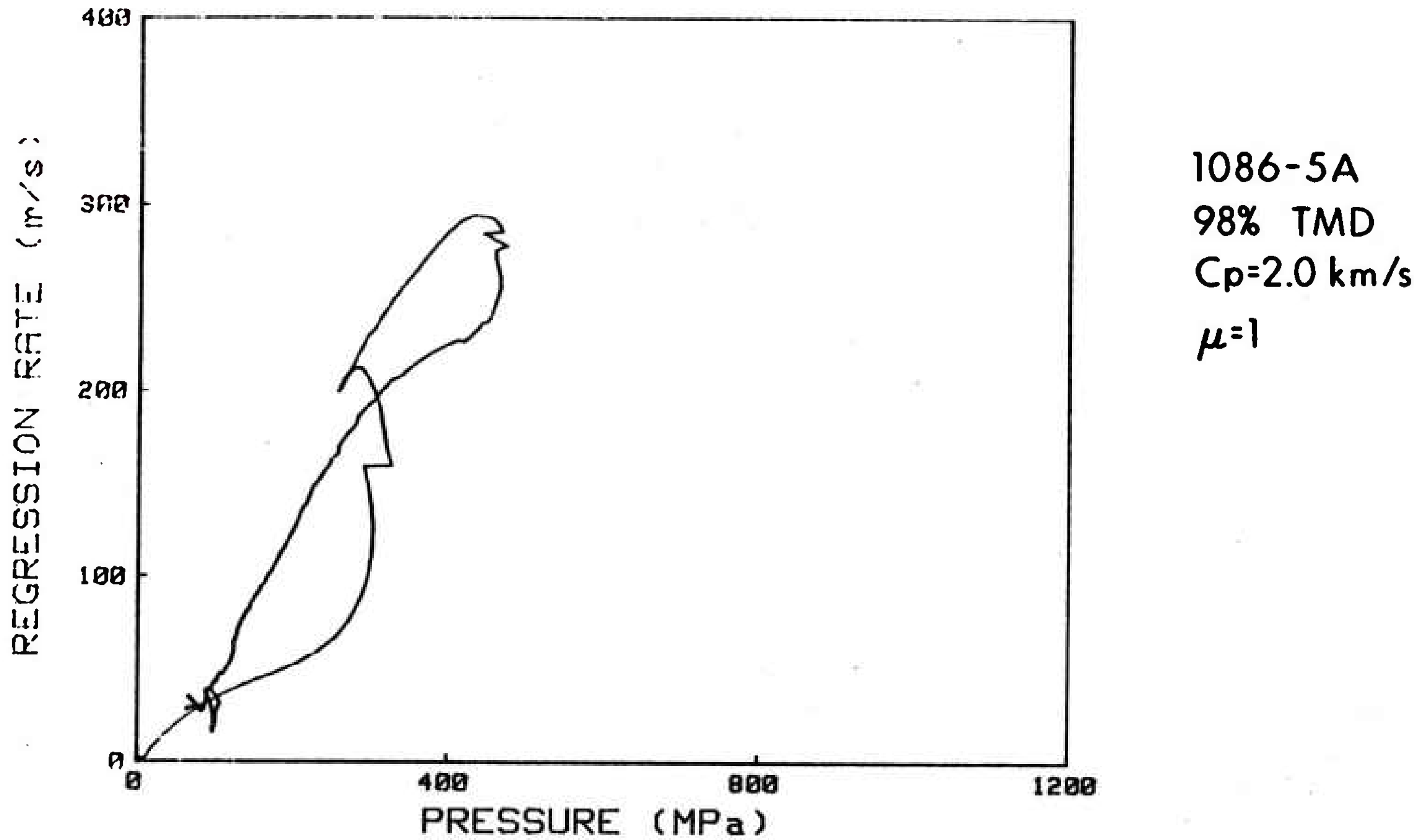

Figure 4. 1086-5A: Regression Rate vs Pressure

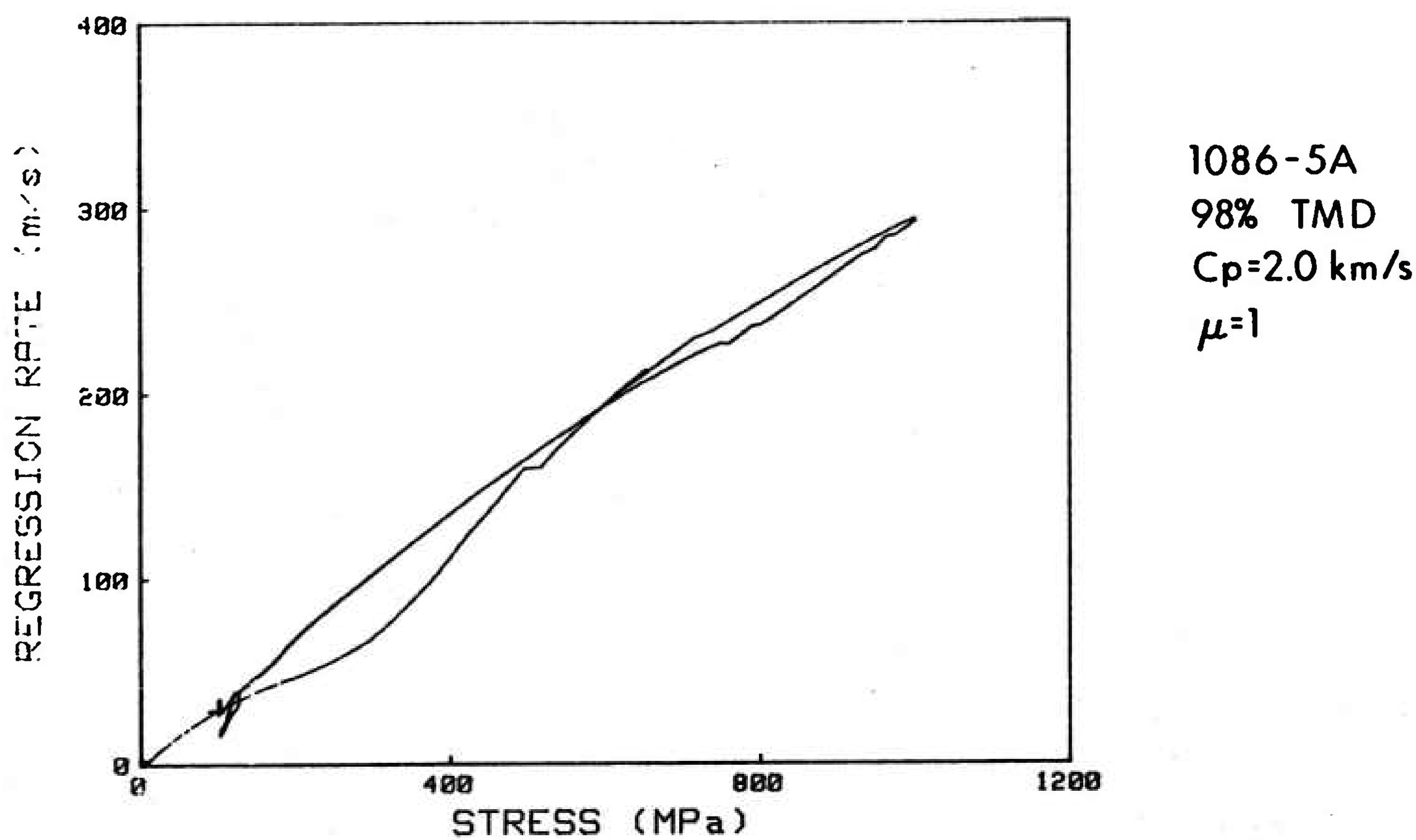

Figure 5. 1086-5A: Regression Rate vs Stress

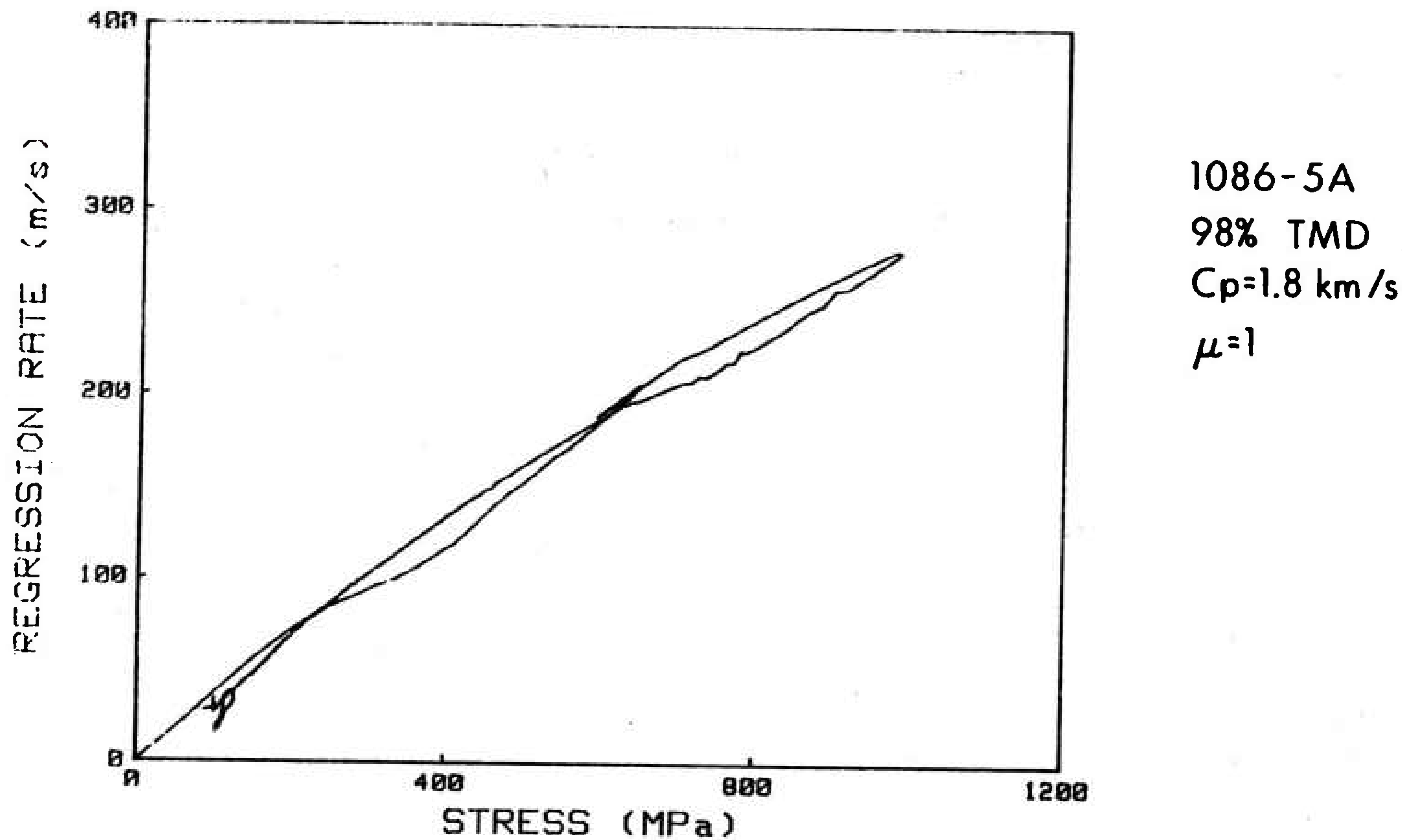

Figure 6. 1086-5A: Regression Rate @C_p = 1.8 km/sec

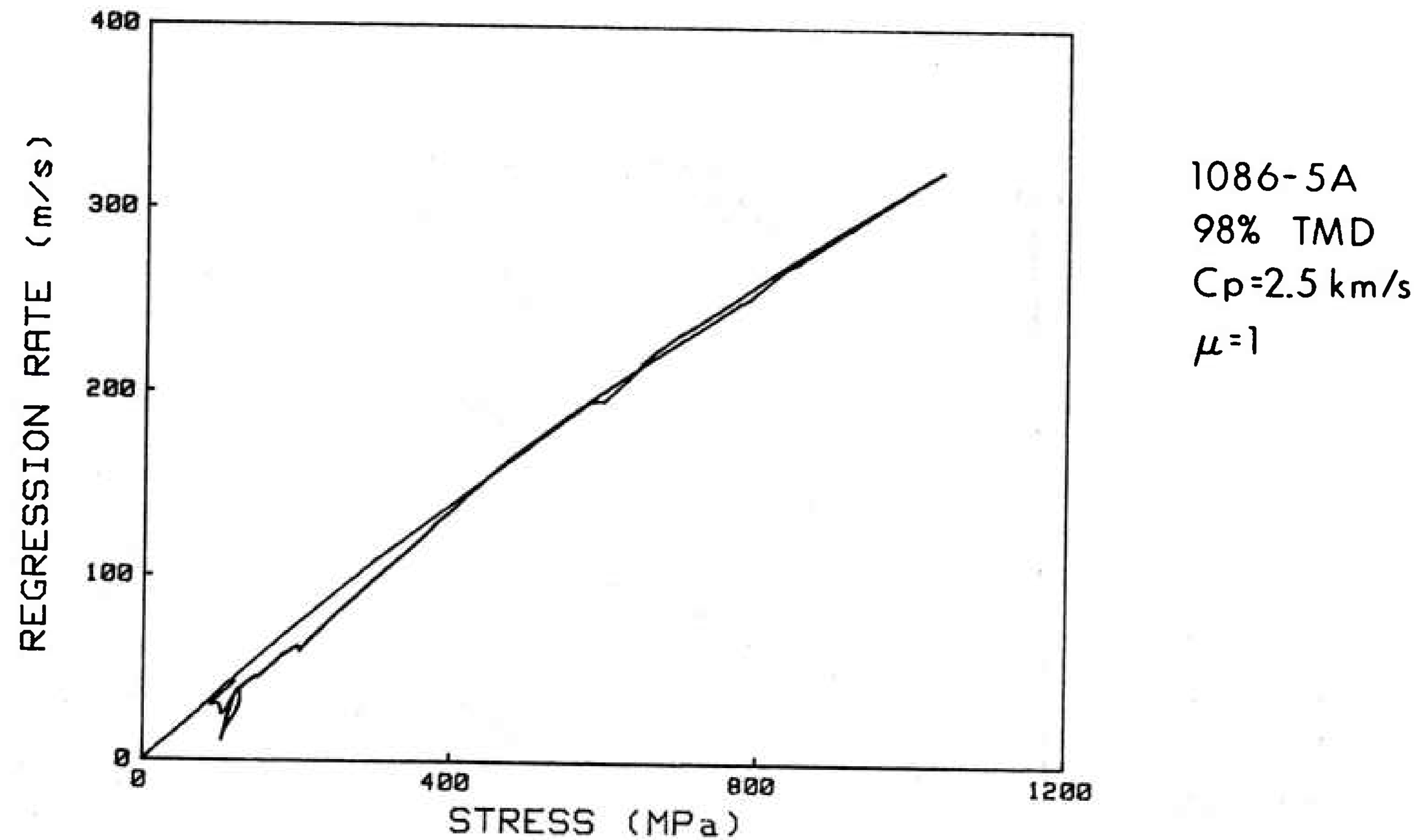

Figure 7. 1086-5A: Regression Rate @ C_p = 2.5 km/sec

A similar parametric study on the effect of wall friction resulted in only minor effects on the apparent burning rate correlations. Further, a simple error analysis of Equation (6) indicates that regression rates lower than about 20 m/s in the pressure region of interest will not yield believable results even given small uncertainties in the measured stress and pressure.

A major concern in our analysis is the experimental observation of the drop of pressure and stress at a point where the analysis predicts that only about one-half of the propellant is consumed (maxima in Figure 3). Theoretical arguments for such a reversal are not yet fully developed. A plausible physical mechanism such as massive propellant column breakup can be postulated. Such refinements are not included in the current model. It is intriguing, however, that at least for the stress vs apparent burning rate, the burning rates march fairly well back down the same path after the peak stress is observed.

3.2 MODERATE BURNING CASE

A sample of 1086-03, (91.5% TMD), although a significantly slower-burning material, also exhibited substantial thrust. The reduced pressure and stress at the combustion gas-propellant interface is depicted in Figure 8. The analysis is terminated at about 350 microseconds after rapid pressurization occurs to eliminate complexities due to wave reflections in the stress rod. Regression rates are shown in Figures 9 and 10. Again, a better correlation is obtained for stress than for pressure. The agreement with the standard closed bomb results[3] of the unconfined samples of the same density is satisfactory in the peak values obtained.

3.3 ANOMALOUS CASE

In two tests of 1086-6B at both 86.6% and 84% TMD, unusual results were obtained. Detailed examination of the pressure and stress gages indicated that both the stress and the pressure (P1) near the stress rod begin to rise almost simultaneously (Figure 11), but the pressures at gages P2, P3, and P4 begin to rise sequentially later in time, as shown in Figure 11. It is our conjecture that in these cases, the fast burning process started at the end-wall and then propagated toward the front end of the sample where ignition due to the igniter first occurred. Flashing down the sidewall or compaction-induced accelerated burning at the endwall are possible mechanisms for such an event. Friction-induced heating and ignition, however, cannot be ruled out. No thrust production was observed for these cases. At this point, it has not been possible to obtain replicate data, due in large part to sample limitations as well as severe instrumentation difficulties. Specifically, for the several fast burning samples that were tested, it has been difficult to maintain strain gage integrity. With only two exceptions, the very high stresses encountered have destroyed the strain patches during the experiment. Further experiments are required.

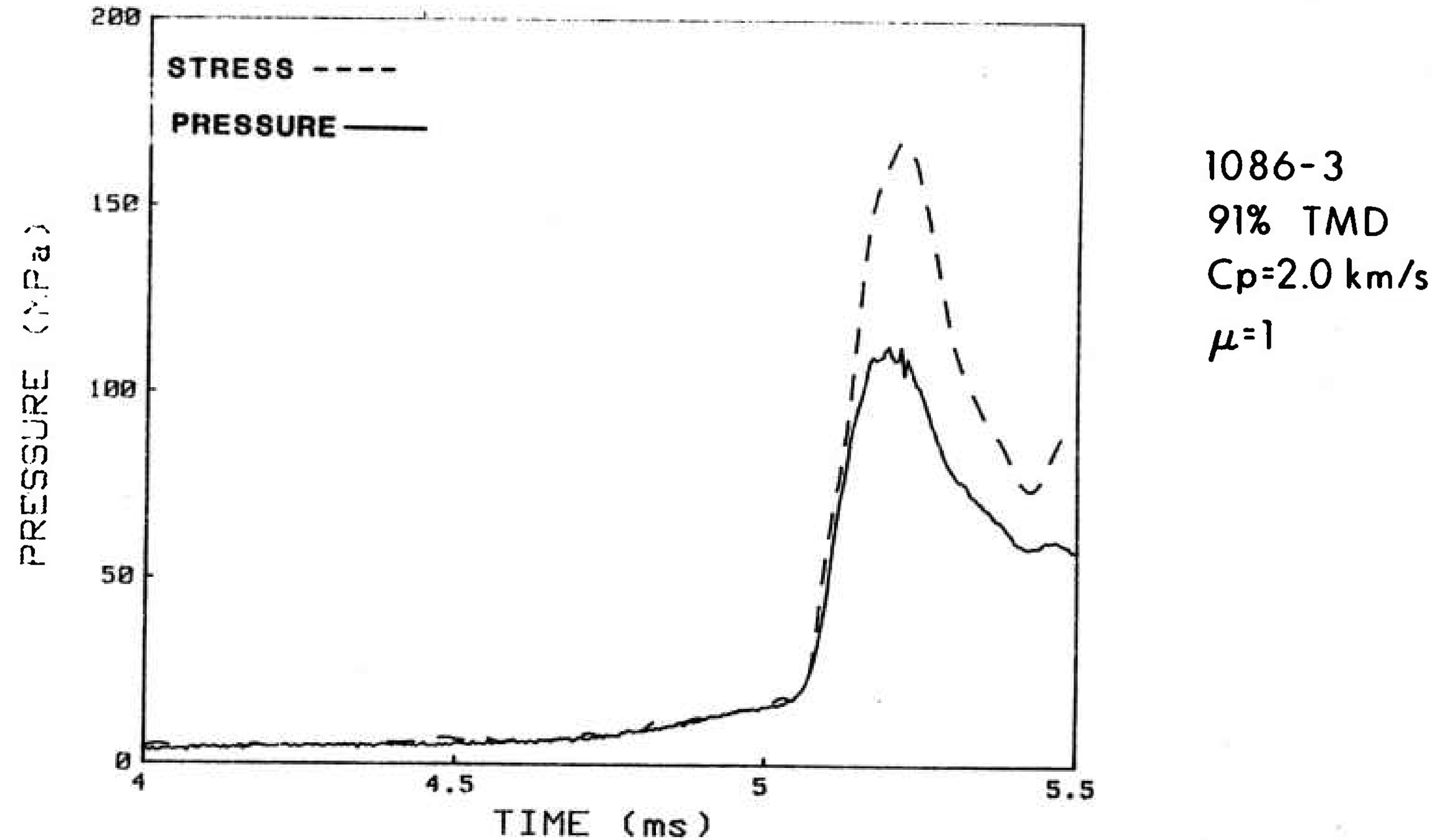

Figure 8. 1086-3: Interface Pressure (-) and Stress (---)

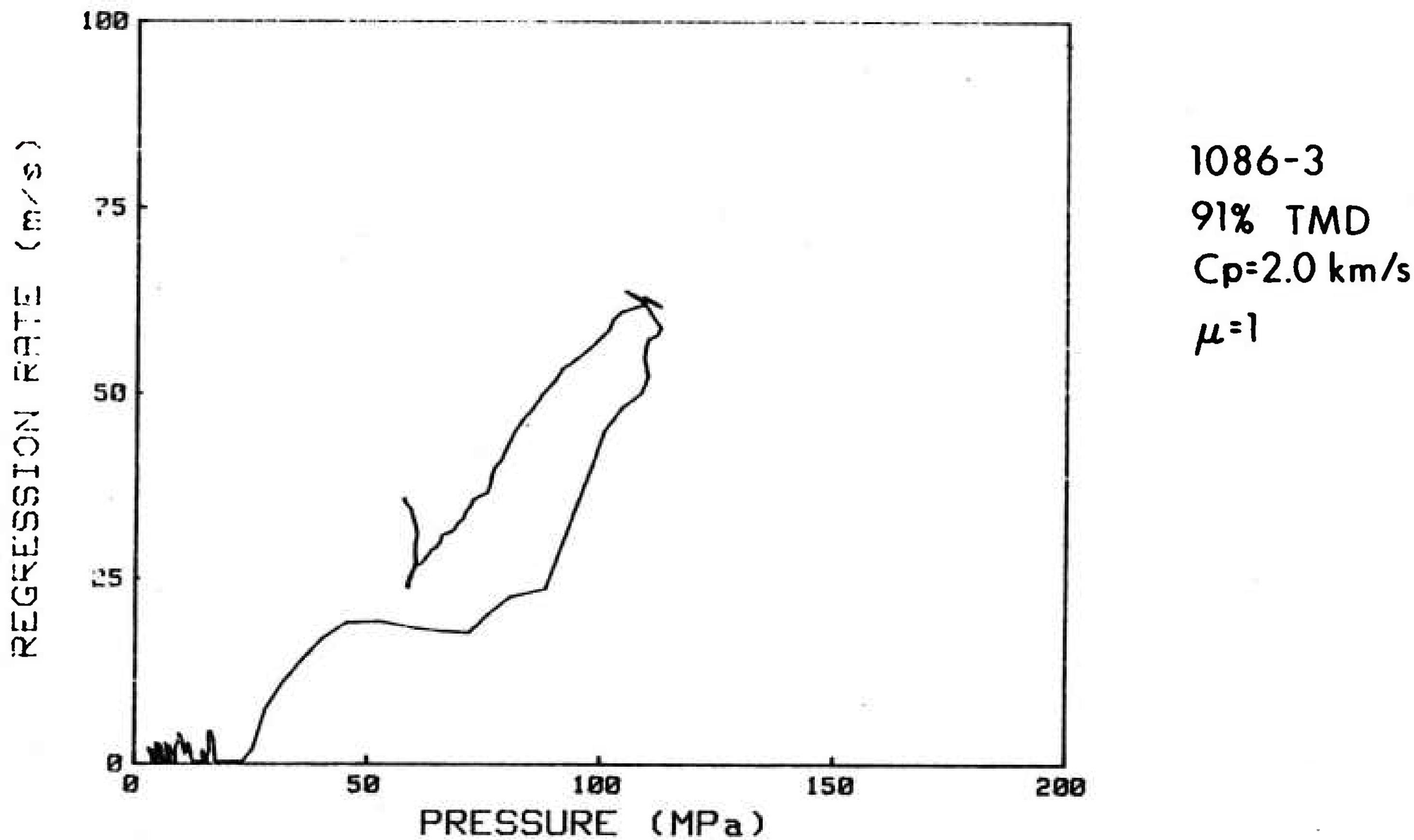

Figure 9. 1086-3: Regression Rate vs Pressure

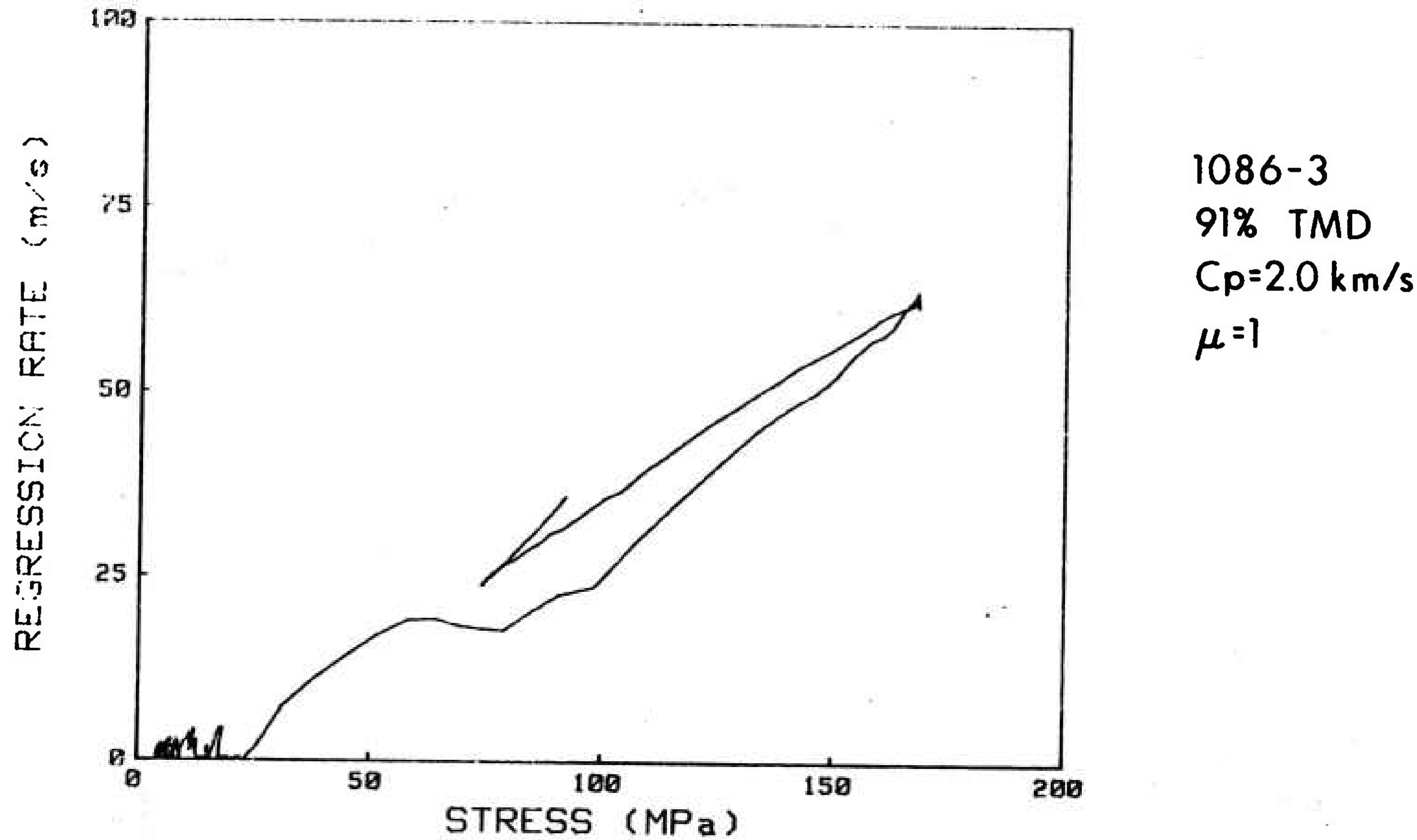

Figure 10. 1086-3: Regression Rate vs Stress

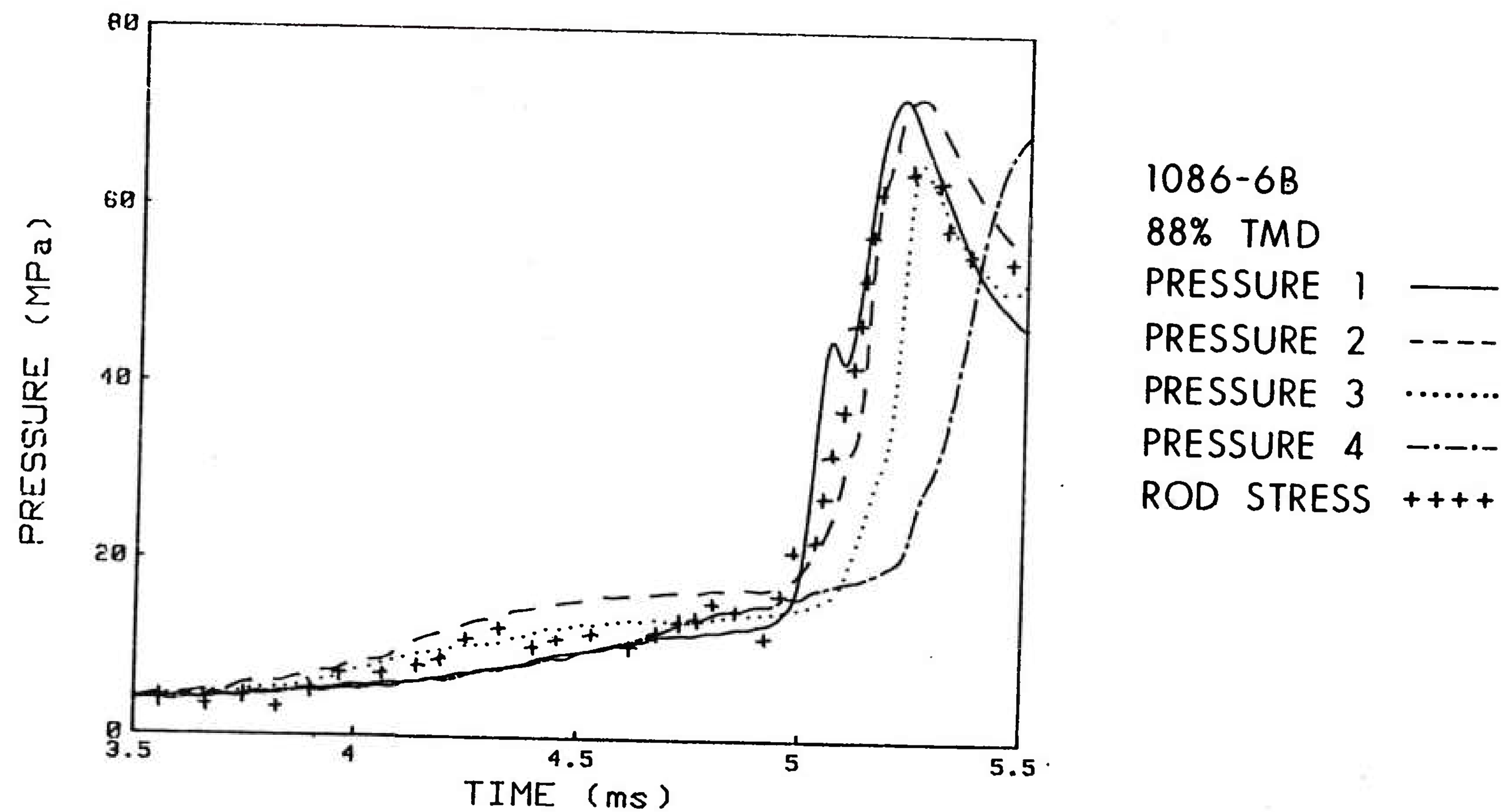

Figure 11. 1086-6B: P1(-), P2(---), P3(...), P4(-.-), RS(+++)

4. CONCLUSIONS AND ISSUES

The analysis employed has certain limitations. It is directly valid only for a reacting flame zone sufficiently thin to be considered quasi-steady. The assumption of elastic behavior of the propellant is also weak at the high dynamic stresses encountered. An explanation for the reversal in pressure and stress at a point where only about one-half of the propellant column is burned requires either a theoretical or an experimental answer, which we are not yet able to provide.

These shortcomings, notwithstanding the experiments described above, have clearly shown significant thrust contributions from VHBR propellant burning. Further, the levels of the thrust generated have been shown to be burning-rate dependent. This, together with the regression rate data obtained earlier,[3] represents a substantial step forward in the development of a traveling charge propellant. Though the precise mechanism of sample burning is not clear, it is possible that a stress-induced breakup is involved in VHBR propellant burning. In that event, a breakup zone not significantly shorter than the sample length would invalidate our model.

The results of the thrust experiments in which the sample ignited on the "wrong" side are strong indications that there are many processes involved with these materials which we do not adequately understand. Effects such as compressive or friction-induced ignition or flamespread along the outer edges of the charge could markedly affect combustion and thrust behavior. Further projected studies, including flash x-ray diagnostics as well as thrust and closed bomb experiments will, hopefully, improve our understanding in these areas.

5. ACKNOWLEDGMENTS

We wish to acknowledge the help and insights provided to us by Mr. Paul Baer, Dr. Douglas Kooker, and Dr. R. Bernecker. In addition, we would like to thank Dr. James Walbert, who supplied us with a powerful Fourier analysis package.

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8. M. Finger, "Hivelite Propellant Characterization," Lawrence Livermore Laboratory Report, UCID-16478, March 1975.

APPENDIX A: DATA REDUCTION PROGRAM

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10   ! ****************************************************************
20   ! *      "THBM17"   --   Burn-Rate Reduction # 17   --   06-OCT-81      *
30   ! ****************************************************************
40    OPTION BASE 1
50    COM SHORT Press_3(2048),Press_2(2048),S(2048),Pfront(2048),Tfront(2048)
60    COM SHORT Timplt(2048),Prsplt(2048),Strplt(2048),Thrplt(2048),Ratplt(2048)
70    COM SHORT G0,Cp,Cs,Rs,Gamma,Ep,B,Gage_off,Sync,Epsilon,Mach_no
80    COM SHORT Tdel,T0,T_end,T_plus,T,T_minus,Thi,Tlo,T_prime,T_stop,T_off
90    COM SHORT L_plus,L,L_minus,L0,L_prime
100   COM SHORT Sig_hi,Sig_lo,Sigma_plus,Sigma,Sigma_minus
110   COM SHORT Num,Den,R_plus,R,R_minus,R_prime,R_last
120   COM SHORT Up_plus,Up,Up_minus,Up_prime,Up_last
130   COM SHORT P_plus,P,P_minus,Pm
140   COM SHORT Ug_plus,Ug,Ug_minus
150   COM SHORT Rg_plus,Rg,Rg_minus
160   COM SHORT Cg_plus,Cg,Cg_minus
170   COM SHORT Rp0,Rp_plus,Rp,Rp_minus,Rp_prime,Rp_last
180   COM SHORT Mu,Radius,Df_hi,Df_lo
190   COM SHORT K1,K2,K3,K4,K5,K6,K7,X
200   COM INTEGER K,M,N,Vsn,Output
210   COM Title$[30],Mode$[1],Ax_lab$(4)[30],Tag$(2)[30]
220  ! ****************************************************************
230   Vsn=17
240   N=2048
250   Ax_lab$(1)="TIME (ms)"
260   Ax_lab$(2)="PRESSURE (MPa)"
270   Ax_lab$(3)="REGRESSION RATE (m/s)"
280   Ax_lab$(4)="STRESS (MPa)"
290  !
300 Top: PRINTER IS 16
310   PRINT PAGE
320   PRINT "                    THRUST REDUCTION -- VSN";Vsn
330   PRINT
340   PRINT "Run options: [1] Std run with initialization"
350   PRINT "             [2] Std run w/o initialization"
360   PRINT "             [3] Plot input data file(s)"
370   PRINT "             [4] Plot results of last std run"
380   PRINT "             [5] Store results of last std run"
390   PRINT "             [6] Retrieve results of a std run"
400   PRINT "             [7] End program ..."
410   K=1
420   INPUT K
430   IF (K<1) OR (K>6) THEN GOTO Finis
440   ON K GOTO Reset,Ask,Graf,Done,Perm,Perm
450  !
460 Perm: ! Store / get generated arrays ...
470  !
480   CALL Results(K,M,Timplt(*),Prsplt(*),Strplt(*),Thrplt(*),Ratplt(*))
490   GOTO Top
500  !
510 Graf: ! Plot input data ...
520  !
530   T_off=0
540   CALL Raw_plot(N,Timplt(*),Prsplt(*),Ax_lab$(1),Ax_lab$(2),Tag$(*),Tdel,T_o
ff)
550   GOTO Top
560  !
570 Reset: ! Initialization ...
580  !
590   Title$="TEST #11  1086-5A  TMD=98%"
600   PRINT "Enter name of PRESSURE 3 file ..."
610   CALL Readf(Press_3(*),N,Tdel,K)
620  ! PRINT "Enter name of PRESSURE 2 file ..."
630  ! CALL Readf(Press_2(*),N,Tdel,K)
640   PRINT "Enter name of ROD STRESS file ..."
650   CALL Readf(S(*),N,Tdel,K)
```

```
660  !
670   G0=386.4       ! in/sec**2
680   Cp=73740       ! in/sec
690   Cs=195600      ! in/sec
700   Rp0=.0537      ! lb/in**3
710   Rs=.2818       ! lb/in**3
720   L0=2           ! in
730   Gamma=1.250    ! ----
740   Ep=1.696E7     ! in-lb/lb
750   B=33.30        ! in**3/lb
760   Gage_off=2     ! in
770   Sync=3.2E-5    ! sec
780   Mu=1           ! ???
790   Radius=.25     ! in
800   Output=0
810   T0=0
820   T_stop=(N-1)*Tdel
830  !
840 Ask: ! Solicit inputs ...
850  !
860   PRINT "Propellant sound speed [in/sec] ...";Cp;" ..."
870   INPUT Cp
880   PRINT "Propellant density [lb/in**3] ...";Rp0;" ..."
890   INPUT Rp0
900   PRINT "Gamma ...";Gamma;" ..."
910   INPUT Gamma
920   PRINT "Energy [in-lb/lb] ...";Ep;" ..."
930   INPUT Ep
940   PRINT "Covolume [in**3/lb] ...";B;" ..."
950   INPUT B
960   PRINT "Wall-friction coefficient ...";Mu;" ..."
970   INPUT Mu
980   PRINT "Sync offset [sec] ...";Sync;" ..."
990   INPUT Sync
1000  PRINT "Title ...";Title$;" ..."
1010  LINPUT Title$
1020  Tag$(1)=Title$
1030  Tag$(2)=" "
1040  PRINT "Output device ...";Output;" ..."
1050  INPUT Output
1060  PRINT "Enter start & end times [sec] ...";T0;",";T_stop;" ..."
1070  INPUT T0,T_stop
1080 !
1090  T_end=T_stop-T0
1100  T_plus=0
1110  L_plus=L0
1120  Cg_plus=1
1130  Ug_plus=0
1140  Rp_plus=Rp0
1150  M=0
1160  Epsilon=.005
1170 !
1180  PRINTER IS Output
1190  PRINT "                         THRUST REDUCTION -- VSN";Vsn
1200  PRINT "                        ";Title$
1210  PRINT
1220  PRINT
1230  PRINT "Input Parameters:"
1240  PRINT USING Fmt0;Rp0,Cp,Gamma
1250 Fmt0:IMAGE "Propellant Density".20X,D.DDDD," lb/in**3"/11X,"Sound Speed",16
X,DDDDDD," in/sec"/11X,"Specific Heat Ratio",3X,D.DDDD
1260  PRINT USING Fmt1;Ep,B,Mu
1270 Fmt1:IMAGE 11X,"Energy",19X,D.DDE," in-lb/lb"/11X,"Covolume".20X,DD.DD," in
**3/lb"/11X,"Wall-Friction Coeff",3X,D.DDDD
1280  PRINT USING Fmt2;Rs,Cs,Sync
```

```
1290 Fmt2:IMAGE "Stress Bar Density",20X,D.DDDD," lb/in**3"/11X,"Sound Speed",16
X,DDDDDD," in/sec"/"Sync Offset",25X,D.DDE," sec"
1300  PRINT
1310  PRINT
1320  PRINT "  TIME   PRESSURE   STRESS    THRUST    LENGTH      U       BURNING
RATE  MACH NO"
1330  PRINT "  (ms)      (MPa)     (MPa)     (MPa)      (mm)    (m/sec)       (m/se
c)"
1340  PRINT
1350 !
1360 L0: ! Uncorrected ...
1370 !
1380  Mode$=" "
1390  T_prime=T_plus+(L0-L_plus)/(Cg_plus-Ug_plus)
1400  CALL Interp(T_prime,T0,Tdel,Press_3(*),P_plus,N)
1410  Tlo=T_plus-L_plus/Cp+Gage_off/Cs-Sync
1420  CALL Interp(Tlo,T0,Tdel,S(*),Sig_lo,N)
1430  Thi=T_plus+L_plus/Cp+Gage_off/Cs-Sync
1440  CALL Interp(Thi,T0,Tdel,S(*),Sig_hi,N)
1450 !
1460 L05: Sigma_plus=Rp_plus*Cp*(Sig_hi-Sig_lo)/(2*Rs*Cs)+(Sig_hi+Sig_lo)/2
1470  Up_plus=G0*(Sig_hi+Sig_lo)/(2*Rs*Cs)+G0*(Sig_hi-Sig_lo)/(2*Rp_plus*Cp)
1480 !
1490 ! Wall-friction correction ...
1500 !
1510  Df_lo=L_plus/Cp-Gage_off/Cs
1520  Df_hi=L_plus/Cp+Gage_off/Cs
1530  Sigma_plus=(2*G0*Radius*Sigma_plus+Cp*Mu*(Sig_hi*Df_hi+Sig_lo*Df_lo))/(2*G
0*Radius-Cp*Mu*(Df_hi+Df_lo))
1540  IF Sigma_plus<=P_plus THEN Sigma_plus=P_plus+1
1550  Up_plus=Up_plus+Mu*((Sigma_plus+Sig_hi)*Df_hi-(Sigma_plus+Sig_lo)*Df_lo)/(
2*Rp_plus*Radius)
1560 !
1570  Num=G0*(Sigma_plus-P_plus)*(Sigma_plus+(Gamma+1)/(Gamma-1)*P_plus)
1580  Den=2*Rp_plus*Rp_plus*(Ep+P_plus*(B-1/Rp_plus)/(Gamma-1))
1590  R_plus=SQR(Num/Den)
1600  Ug_plus=Up_plus-G0*(Sigma_plus-P_plus)/(Rp_plus*R_plus)
1610  Rg_plus=-Rp_plus*R_plus/(Ug_plus-Up_plus-R_plus)
1620  Cg_plus=SQR(Gamma*G0*(P_plus+14.7)/(Rg_plus*(1-B*Rg_plus)))
1630  Rp_prime=Rp_plus
1640  Rp_plus=Rp0+G0*Sigma_plus/Cp^2
1650  IF ABS((Rp_plus-Rp_prime)/Rp_prime)>Epsilon THEN GOTO L05
1660 !
1670 L1: ! Store & setup next step ...
1680 !
1690  M=M+1
1700  Timplt(M)=(T_plus+T0)*1000                          ! ms
1710  Prsplt(M)=P_plus/1000*6.89475                       ! MPa
1720  Strplt(M)=Sigma_plus/1000*6.89475                   ! MPa
1730  Thrplt(M)=(Sigma_plus-P_plus)/1000*6.89475          ! MPa
1740  Ratplt(M)=R_plus*.0254                              ! m/s
1750  Tfront(M)=T_plus                                    ! sec
1760  Pfront(M)=P_plus                                    ! psi
1770  R_prime=R_plus*.0254                                ! m/s
1780  L_prime=L_plus*25.400000                            ! mm
1790  Up_prime=Up_plus*.0254                              ! m/s
1800  Mach_no=ABS(Ug_plus/Cg_plus)                        ! ----
1810  R_last=R_plus
1820  Up_last=Up_plus
1830  Rp_last=Rp_plus
1840 !
1850  PRINT USING Fmt3;Timplt(M),Prsplt(M),Strplt(M),Thrplt(M),L_prime,Up_prime,
R_prime,Mach_no,Mode$
1860 Fmt3: IMAGE DD.DDD,4X,DDDD.D,4X,DDDD.D,4X,DDDD.D,5X,DD.DD,4X.DDD.DDD.5X,DDD
.DDD,5X,D.DD,X,A
1870 !
```

```
1880 ! New time T_plus ...
1890 !
1900 L15: T_plus=T_plus+Tdel
1910  IF T_plus>T_end THEN Done
1920  L_plus=L_plus-(R_last+Up_last)*Tdel
1930  IF L_plus<=0 THEN Done
1940  IF M<2 THEN GOTO L0
1950  T=Tfront(M)
1960  K=0
1970  R=R_last
1980  Up=Up_last
1990  Rp=Rp_last
2000 !
2010 L2: ! Determine T & values at time T ...
2020 !
2030  CALL Interp2(T,Tfront(*),Pfront(*),P,M)
2040  L=L_plus+(R+Up)*(T_plus-T)
2050  Tlo=T-L/Cp+Gage_off/Cs-Sync
2060  CALL Interp(Tlo,T0,Tdel,S(*),Sig_lo,N)
2070  Thi=T+L/Cp+Gage_off/Cs-Sync
2080  CALL Interp(Thi,T0,Tdel,S(*),Sig_hi,N)
2090  Sigma=Rp*Cp*(Sig_hi-Sig_lo)/(2*Rs*Cs)+(Sig_hi+Sig_lo)/2
2100  Up=G0*(Sig_hi+Sig_lo)/(2*Rs*Cs)+G0*(Sig_hi-Sig_lo)/(2*Rp*Cp)
2110 !
2120 ! Wall-friction correction ...
2130 !
2140  Df_lo=L/Cp-Gage_off/Cs
2150  Df_hi=L/Cp+Gage_off/Cs
2160  Sigma=(2+G0*Radius*Sigma+Cp*Mu*(Sig_hi*Df_hi+Sig_lo*Df_lo))/(2*G0*Radius-C
p*Mu*(Df_hi+Df_lo))
2170  IF Sigma<=P THEN Sigma=P+1
2180  Up=Up+Mu*((Sigma+Sig_hi)*Df_hi-(Sigma+Sig_lo)*Df_lo)/(2*Rp*Radius)
2190 !
2200  Num=G0*(Sigma-P)*(Sigma+(Gamma+1)/(Gamma-1)*P)
2210  Den=2*Rp*Rp*(Ep+P*(B-1/Rp)/(Gamma-1))
2220  R=SQR(Num/Den)
2230  Ug=Up-G0*(Sigma-P)/(Rp+R)
2240  Rg=-Rp*R/(Ug-Up-R)
2250  Cg=SQR(Gamma*G0*(P+14.7)/(Rg*(1-B*Rg)))
2260  Rp=Rp0+G0*Sigma/Cp^2
2270 !
2280  T_prime=T_plus-(L0-L)/(Ug+Cg)
2290  IF ABS((T_prime-T)/T)<Epsilon THEN GOTO L3
2300  T=(T_prime+T)/2
2310  K=K+1
2320  IF K<25 THEN GOTO L2
2330  GOTO L15
2340 !
2350 L3: T_minus=T-Tdel
2360  R_minus=R
2370  Up_minus=Up
2380  Rp_minus=Rp
2390  K=0
2400 !
2410 L4: ! Determine T_minus & values at T_minus ...
2420 !
2430  CALL Interp2(T_minus,Tfront(*),Pfront(*),P_minus,M)
2440  L_minus=L_plus+(R+Up)*(T_plus-T)+(R_minus+Up_minus)*(T-T_minus)
2450  Tlo=T_minus-L_minus/Cp+Gage_off/Cs-Sync
2460  CALL Interp(Tlo,T0,Tdel,S(*),Sig_lo,N)
2470  Thi=T_minus+L_minus/Cp+Gage_off/Cs-Sync
2480  CALL Interp(Thi,T0,Tdel,S(*),Sig_hi,N)
2490  Sigma_minus=Rp_minus*Cp*(Sig_hi-Sig_lo)/(2*Rs*Cs)+(Sig_hi+Sig_lo)/2
2500  Up_minus=G0*(Sig_hi+Sig_lo)/(2+Rs+Cs)+G0*(Sig_hi-Sig_lo)/(2*Rp_minus*Cp)
2510 !
2520 ! Wall-friction correction ...
```

```
2530 !
2540  Df_lo=L_minus/Cp-Gage_off/Cs
2550  Df_hi=L_minus/Cp+Gage_off/Cs
2560  Sigma_minus=(2*G0*Radius*Sigma_minus+Cp*Mu*(Sig_hi+Df_hi+Sig_lo*Df_lo))/(2
*G0*Radius-Cp*Mu*(Df_hi+Df_lo))
2570  IF Sigma_minus<=P_minus THEN Sigma_minus=P_minus+1
2580  Up_minus=Up_minus+Mu*((Sigma_minus+Sig_hi)*Df_hi-(Sigma_minus+Sig_lo)*Df_l
o)/(2*Rp_minus*Radius)
2590 !
2600  Num=G0*(Sigma_minus-P_minus)*(Sigma_minus+(Gamma+1)/(Gamma-1)*P_minus)
2610  Den=2*Rp_minus*Rp_minus*(Ep+P_minus*(B-1/Rp_minus)/(Gamma-1))
2620  R_minus=SQR(Num/Den)
2630  Ug_minus=Up_minus-G0*(Sigma_minus-P_minus)/(Rp_minus*R_minus)
2640  Rg_minus=-Rp_minus*R_minus/(Ug_minus-Up_minus-R_minus)
2650  Cg_minus=SQR(Gamma*G0*(P_minus+14.7)/(Rg_minus*(1-B*Rg_minus)))
2660  Rp_minus=Rp0+G0*Sigma_minus/Cp^2
2670 !
2680  T_prime=T-(L_minus-L0)/(Ug-Cg)
2690  IF ABS((T_minus-T_prime)/T_minus)<Epsilon THEN GOTO L5
2700  T_minus=T_prime
2710  K=K+1
2720  IF K<25 THEN GOTO L4
2730  GOTO L15
2740 !
2750 L5: ! Determine stress at reaction front ...
2760 !
2770  Rp_plus=Rp
2780  Cg_plus=Cg
2790  Ug_plus=Ug
2800  CALL Interp(T,T0,Tdel,Press_3(*),Pm,N)
2810  Tlo=T_plus-L_plus/Cp+Gage_off/Cs-Sync
2820  CALL Interp(Tlo,T0,Tdel,S(*),Sig_lo,N)
2830  Thi=T_plus+L_plus/Cp+Gage_off/Cs-Sync
2840  CALL Interp(Thi,T0,Tdel,S(*),Sig_hi,N)
2850 !
2860 L55: Sigma_plus=Rp_plus*Cp*(Sig_hi-Sig_lo)/(2*Rs*Cs)+(Sig_hi+Sig_lo)/2
2870  Up_plus=G0*(Sig_hi+Sig_lo)/(2*Rs*Cs)+G0*(Sig_hi-Sig_lo)/(2*Rp_plus*Cp)
2880 !
2890 ! Wall-friction correction ...
2900 !
2910  Df_lo=L_plus/Cp-Gage_off/Cs
2920  Df_hi=L_plus/Cp+Gage_off/Cs
2930  Sigma_plus=(2*G0*Radius*Sigma_plus+Cp*Mu*(Sig_hi+Df_hi+Sig_lo*Df_lo))/(2*G
0*Radius-Cp*Mu*(Df_hi+Df_lo))
2940  Up_plus=Up_plus+Mu*((Sigma_plus+Sig_hi)+Df_hi-(Sigma_plus+Sig_lo)+Df_lo)/(
2*Rp_plus*Radius)
2950 !
2960 L6: ! Solve cubic for P_plus ...
2970 !
2980  K1=2*Pm-P_minus+Rg*Cg*(Ug_minus-Up_plus)/G0
2990  K2=2*Rg^2*Cg^2/G0
3000  K3=(B-1/Rp_plus)/(Gamma-1)
3010  K4=(Gamma+1)/(Gamma-1)
3020  K5=Sigma_plus-2*K1*K4+K2*K3
3030  K6=-2*K1*Sigma_plus+K1^2*K4-K2*Sigma_plus*K3+K2*Ep
3040  K7=K1^2*Sigma_plus-K2*Ep*Sigma_plus
3050  X=P
3060 !
3070 L7: Fx=K4*X^3+K5*X^2+K6*X+K7
3080  Fx_prime=3*K4*X^2+2*K5*X+K6
3090  P_plus=X-Fx/Fx_prime
3100  IF ABS((X-P_plus)/P_plus)<.0001 THEN GOTO L8
3110  X=P_plus
3120  GOTO L7
3130 !
3140 L8: ! Determine values at time T_plus when P_plus found ...
```

```
3150 !
3160  Mode$="*"
3170  IF P_plus>0 THEN GOTO L9
3180  Mode$="?"
3190  T_prime=T_plus+(L0-L_plus)/(Cg_plus-Ug_plus)
3200  CALL Interp(T_prime,T0,Tdel,Press_3(*),P_plus,N)
3210 L9: IF Sigma_plus<=P_plus THEN Sigma_plus=P_plus+1
3220 !
3230  Num=G0*(Sigma_plus-P_plus)*(Sigma_plus+(Gamma+1)/(Gamma-1)*P_plus)
3240  Den=2*Rp_plus+Rp_plus*(Ep+P_plus*(B-1/Rp_plus)/(Gamma-1))
3250  R_plus=SQR(Num/Den)
3260  Ug_plus=Up_plus-G0*(Sigma_plus-P_plus)/(Rp_plus*R_plus)
3270  Rg_plus=-Rp_plus*R_plus/(Ug_plus-Up_plus-R_plus)
3280  Cg_plus=SQR(Gamma*G0*(P_plus+14.7)/(Rg_plus*(1-B*Rg_plus)))
3290  Rp_prime=Rp_plus
3300  Rp_plus=Rp0+G0*Sigma_plus/Cp^2
3310  IF ABS((Rp_plus-Rp_prime)/Rp_prime)<Epsilon THEN GOTO L1
3320  GOTO L55
3330 !
3340 Done: ! Run complete; time to plot ...
3350 !
3360  PRINT
3370  PRINT
3380  PRINTER IS 16
3390 !
3400  PRINT PAGE
3410  K=1
3420  PRINT "Burning Rate vs. Stress ..."
3430  CALL Plotit(K,M,Strplt(*),Ratplt(*),Ax_lab$(4),Ax_lab$(3),Tag$(*))
3440  PRINT "Pressure vs. Time ..."
3450  CALL Plotit(K,M,Timplt(*),Prsplt(*),Ax_lab$(1),Ax_lab$(2),Tag$(*))
3460  PRINT "Burning Rate vs. Thrust ..."
3470  CALL Plotit(K,M,Thrplt(*),Ratplt(*),Ax_lab$(2),Ax_lab$(3),Tag$(*))
3480  PRINT "Stress vs. Time ..."
3490  CALL Plotit(K,M,Timplt(*),Strplt(*),Ax_lab$(1),Ax_lab$(4),Tag$(*))
3500  PRINT "Thrust vs. Time ..."
3510  CALL Plotit(K,M,Timplt(*),Thrplt(*),Ax_lab$(1),Ax_lab$(2),Tag$(*))
3520  PRINT "Burning Rate vs. Time ..."
3530  CALL Plotit(K,M,Timplt(*),Ratplt(*),Ax_lab$(1),Ax_lab$(3),Tag$(*))
3540  PRINT "Burning Rate vs. Pressure ..."
3550  CALL Plotit(K,M,Prsplt(*),Ratplt(*),Ax_lab$(2),Ax_lab$(3),Tag$(*))
3560 !
3570  PEN -1
3580 Finis: STOP
3590  END
3600 ! *******************************************************************
3610  SUB Interp(SHORT Time,SHORT T0,SHORT Tdel,SHORT Q(*),SHORT Ans,INTEGER Max
)
3620  OPTION BASE 1
3630  SHORT T1
3640  INTEGER N1,Nr
3650 !
3660  N1=INT((Time+T0)/Tdel)+1
3670  IF N1<1 THEN N1=1
3680  IF N1>Max-1 THEN N1=Max-1
3690  Nr=N1+1
3700  T1=(N1-1)*Tdel-T0
3710  Ans=Q(N1)+(Q(Nr)-Q(N1))*(Time-T1)/Tdel
3720 !
3730  SUBEND
3740 ! *******************************************************************
3750  SUB Readf(SHORT Out(*),INTEGER N,SHORT Delta,INTEGER Iflag)
3760  OPTION BASE 1
3770  SHORT Get(2085)
3780  INTEGER I
3790  DIM Fname$[6]
```

```
3800 !
3810  INPUT Fname$
3820  Iflag=1
3830  IF Fname$="NONE" THEN GOTO Bypass
3840  Iflag=0
3850 !
3860  FREAD Fname$&":C12",Get(*)
3870  Delta=Get(37)/1000
3880 !
3890  FOR I=1 TO N
3900  Out(I)=Get(I+37)*1000
3910  NEXT I
3920 !
3930 Bypass: ! Done ...
3940 !
3950  SUBEND
3960 ! ******************************************************************
3970  SUB Plotit(INTEGER Nlo,INTEGER Nhi,SHORT X(*),SHORT Y(*),X_lab$,Y_lab$,Tag
$(*))
3980  OPTION BASE 1
3990  SHORT Xaxlen,Yaxlen,Offset,Xmin,Xmax,Xdel,Ymin,Ymax,Ydel,Twid,Thgt,Tspec
4000  SHORT Amin,Amax,Bmin,Bmax,Xlim,Ylim,Xpos,Ypos,Cwid,Chgt,Cspec,Fact
4010  INTEGER J,L_code,Over,Loop
4020  DIM V$[30]
4030 !
4040  Over=0
4050  PRINT "Overlay on current plot [-1=Escape, 0=No, 1=Yes] ..."
4060  INPUT Over
4070  IF Over=1 THEN GOTO Overlay
4080  IF Over<0 THEN GOTO Return
4090 !
4100  Offset=25.4
4110  Xaxlen=5
4120  Yaxlen=4
4130  PRINT "Enter x- & y-axis lengths [";Xaxlen;Yaxlen;" in] ..."
4140  INPUT Xaxlen,Yaxlen
4150 !
4160  Amin=Amax=X(Nlo)
4170  Bmin=Bmax=Y(Nlo)
4180  FOR J=Nlo TO Nhi
4190  IF X(J)<Amin THEN Amin=X(J)
4200  IF X(J)>Amax THEN Amax=X(J)
4210  IF Y(J)<Bmin THEN Bmin=Y(J)
4220  IF Y(J)>Bmax THEN Bmax=Y(J)
4230  NEXT J
4240 !
4250  PRINT "Enter Xmin, Xmax, & Xdel [range:";Amin;Amax;X_lab$;"] ..."
4260  INPUT Xmin,Xmax,Xdel
4270  PRINT "Enter Ymin, Ymax, & Ydel [range:";Bmin;Bmax;Y_lab$;"] ..."
4280  INPUT Ymin,Ymax,Ydel
4290  PRINT "Title 1 ... ";Tag$(1)
4300  LINPUT Tag$(1)
4310  PRINT "Title 2 ... ";Tag$(2)
4320  LINPUT Tag$(2)
4330 !
4340  PLOTTER IS "9872A"
4350  DEG
4360  Xlim=25.4*Xaxlen+Offset
4370  Ylim=25.4*Yaxlen+Offset
4380  LIMIT 0,Xlim+Offset,0,Ylim+Offset
4390  SCALE 0,Xlim+Offset,0,Ylim+Offset
4400 !
4410  Chgt=.15*25.4
4420  Cwid=9/15*Chgt
4430  Fact=1.5
4440  Cspec=Chgt*100*MAX(1,RATIO)/(Xlim+Offset)
```

```
4450  Thgt=Chgt*Fact
4460  Twid=Cwid*Fact
4470  Tspec=Thgt*100*MAX(1,RATIO)/(Xlim+Offset)
4480 !
4490  CSIZE Tspec
4500  Xpos=.5*(Xlim+Offset-LEN(X_labs$)*Twid)
4510  Ypos=Offset-2.5*Chgt
4520  MOVE Xpos,Ypos
4530  LABEL X_labs$
4540 !
4550  CSIZE Cspec
4560  Loop=INT(1.01*(Xmax-Xmin)/Xdel)+1
4570 !
4580  FOR J=1 TO Loop
4590  V$=VAL$(Xmin+(J-1)*Xdel)
4600  Xpos=Offset+(J-1)*(Xlim-Offset)/(Loop-1)-.5*LEN(V$)*Cwid
4610  Ypos=Offset-Chgt
4620  MOVE Xpos,Ypos
4630  LABEL V$
4640  NEXT J
4650 !
4660  LDIR 90
4670  CSIZE Tspec
4680  Xpos=Offset-6*Cwid
4690  Ypos=.5*(Ylim+Offset-LEN(Y_labs$)*Twid)
4700  MOVE Xpos,Ypos
4710  LABEL Y_labs$
4720 !
4730  LDIR 0
4740  CSIZE Cspec
4750  Loop=INT(1.01*(Ymax-Ymin)/Ydel)+1
4760 !
4770  FOR J=1 TO Loop
4780  V$=VAL$(Ymin+(J-1)*Ydel)
4790  Xpos=Offset-(.5+LEN(V$))*Cwid
4800  Ypos=Offset+(J-1)*(Ylim-Offset)/(Loop-1)-.275*Chgt
4810  MOVE Xpos,Ypos
4820  LABEL V$
4830  NEXT J
4840 !
4850  MOVE 2*Offset,Ylim+.75*Offset
4860  LABEL Tag$(1)
4870  MOVE 2*Offset,Ylim+.25*Offset
4880  LABEL Tag$(2)
4890 !
4900  LIMIT Offset,Xlim,Offset,Ylim
4910  SCALE Xmin,Xmax,Ymin,Ymax
4920  FRAME
4930  AXES Xdel,Ydel,Xmin,Ymin
4940 !
4950 Overlay: ! Lay down next curve ...
4960 !
4970  L_code=1
4980  PRINT "Enter line-type code [1 thru 10] ..."
4990  INPUT L_code
5000  LINE TYPE L_code
5010  PENUP
5020 !
5030  FOR J=Nlo TO Nhi
5040  PLOT X(J),Y(J)
5050  NEXT J
5060  PENUP
5070  LINE TYPE 1
5080 !
5090 Return: ! Done ...
5100 !
```

```
5110  PRINT
5120  SUBEND
5130  ! ********************************************************************
5140  SUB Raw_plot(INTEGER N,SHORT Eks(*),SHORT Wye(*),X1$,Y1$,Title$(*),SHORT D
elta,SHORT Offset)
5150  OPTION BASE 1
5160  SHORT Tmin,Tmax
5170  INTEGER I,Nlo,Nhi
5180  !
5190  Title$(1)=Title$(2)=" "
5200 Top: PRINT PAGE
5210  PRINT "Enter name of data file ..."
5220  CALL Readf(Wye(*),N,Delta,I)
5230  IF I=1 THEN GOTO Ask
5240  Delta=Delta*1000
5250  PRINT "Enter desired offset [";Offset;X1$;"] ..."
5260  INPUT Offset
5270  !
5280  FOR I=1 TO N
5290  Eks(I)=(I-1)*Delta+Offset
5300  Wye(I)=Wye(I)/1000*6.89475
5310  NEXT I
5320  !
5330 Ask: PRINT "Select plot window [range:";Eks(1);Eks(N);X1$;"] ..."
5340  Tmin=Eks(1)
5350  Tmax=Eks(N)
5360  INPUT Tmin,Tmax
5370  IF Tmin>=Tmax THEN GOTO Ask
5380  Nlo=(Tmin-Offset)/Delta+1
5390  IF Nlo<1 THEN Nlo=1
5400  Nhi=(Tmax-Offset)/Delta+1
5410  IF Nhi>N THEN Nhi=N
5420  !
5430  CALL Plotit(Nlo,Nhi,Eks(*),Wye(*),X1$,Y1$,Title$(*))
5440  PRINT "Plotting complete [0=No, 1=Yes] ..."
5450  I=0
5460  INPUT I
5470  IF I=0 THEN GOTO Top
5480  !
5490  PEN -1
5500  SUBEND
5510  ! ********************************************************************
5520  SUB Interp2(SHORT Time,SHORT T(*),SHORT Q(*),SHORT Ans,INTEGER Max)
5530  OPTION BASE 1
5540  INTEGER Nl,Nr
5550  !
5560  FOR Nl=Max-1 TO 1 STEP -1
5570  IF Time>T(Nl) THEN GOTO Hit
5580  NEXT Nl
5590  !
5600  Nl=1
5610 Hit: Nr=Nl+1
5620  Ans=Q(Nl)+(Q(Nr)-Q(Nl))*(Time-T(Nl))/(T(Nr)-T(Nl))
5630  IF Ans<=0 THEN Ans=Q(Nr)
5640  !
5650  SUBEND
5660  ! ********************************************************************
5670  SUB Results(INTEGER Opt,INTEGER M,SHORT Time(*),SHORT P(*),SHORT S(*),SHOR
T T(*),SHORT R(*))
5680  OPTION BASE 1
5690  DIM Fname$[6],Fullname$[10]
5700  !
5710  PRINT
5720  PRINT "Enter name of data file ..."
5730  INPUT Fname$
5740  Fullname$=Fname$&":C12"
```

```
5750 !
5760  IF Opt=6 THEN GOTO Retrieve
5770 !
5780 ! Store arrays ...
5790 !
5800  CREATE Fullname$,161
5810  ASSIGN #1 TO Fullname$
5820  BUFFER #1
5830  PRINT #1;M,Time(*),P(*),S(*),T(*),R(*)
5840  ASSIGN #1 TO *
5850  GOTO Done
5860 !
5870 Retrieve: ! Get arrays ...
5880 !
5890  ASSIGN #1 TO Fullname$
5900  BUFFER #1
5910  READ #1;M,Time(*),P(*),S(*),T(*),R(*)
5920  ASSIGN #1 TO *
5930 !
5940 Done: ! Return ...
5950 !
5960  SUBEND
5970 ! *******************************************************************
5980 ! *END*                          *END*                          *END*
5990 ! *******************************************************************
```

APPENDIX B: SAMPLE RUN OF 1086-5A

THRUST REDUCTION -- VSN 17

Input Parameters:

Propellant	Density	.0537	lb/in**3
	Sound Speed	118110	in/sec
	Specific Heat Ratio	1.2500	
	Energy	1.70E+07	in-lb/lb
	Covolume	33.80	in**3/lb
	Wall-Friction Coeff	1.0000	
Stress Bar	Density	.2818	lb/in**3
	Sound Speed	195600	in/sec
Sync Offset		2.40E-05	sec

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
.800	2.9	3.8	.9	50.80	.090	1.216	.49
.801	2.9	3.8	.9	50.80	.061	1.182	.48
.802	2.9	3.7	.8	50.80	.029	1.133	.46 *
.803	2.9	3.6	.7	50.80	-.004	1.067	.43 *
.804	2.9	3.5	.6	50.80	-.036	.984	.40 *
.805	2.9	3.4	.5	50.79	-.066	.883	.36 *
.806	2.9	3.3	.4	50.79	-.092	.760	.31 *
.807	2.9	3.2	.2	50.79	-.115	.615	.25 *
.808	2.9	3.0	.1	50.79	-.132	.432	.18 *
.809	2.9	2.9	.0	50.79	-.143	.128	.05 *
.810	2.8	2.8	.0	50.79	-.149	.029	.01 *
.811	2.8	2.8	.0	50.79	-.150	.117	.05 *
.812	2.7	2.7	.0	50.79	-.146	.090	.04 *
.813	2.7	2.7	.0	50.79	-.138	.182	.08 *
.814	2.7	2.7	.0	50.79	-.127	.098	.04 *
.815	2.7	2.7	.0	50.79	-.113	.211	.09 *
.816	2.8	2.8	.0	50.79	-.097	.006	.00 *
.817	2.8	2.8	.0	50.79	-.080	.087	.04 *
.818	2.9	2.9	.0	50.79	-.061	.080	.03 *
.819	3.0	3.0	.0	50.79	-.042	.157	.06 *
.820	3.0	3.1	.1	50.79	-.022	.325	.13 *
.821	3.0	3.2	.2	50.79	-.003	.537	.21 *
.822	3.0	3.3	.3	50.79	.017	.725	.29 *
.823	3.0	3.4	.5	50.79	.036	.864	.34 *
.824	3.0	3.6	.6	50.79	.054	.971	.39 *
.825	3.0	3.7	.7	50.79	.072	1.061	.42 *
.826	3.0	3.8	.8	50.79	.088	1.143	.45 *
.827	3.0	3.9	.9	50.79	.102	1.214	.48 *
.828	3.0	4.0	1.0	50.78	.114	1.271	.50 *
.829	3.0	4.0	1.0	50.78	.124	1.313	.52 *
.830	3.0	4.1	1.1	50.78	.133	1.338	.53 *
.831	3.0	4.1	1.1	50.78	.139	1.342	.53 *
.832	3.0	4.0	1.1	50.78	.144	1.325	.53 *
.833	3.0	4.0	1.0	50.78	.147	1.283	.51 *
.834	3.0	3.9	.9	50.78	.149	1.217	.49 *
.835	3.0	3.7	.8	50.77	.150	1.124	.45 *
.836	3.0	3.6	.6	50.77	.151	1.003	.40 *
.837	3.0	3.4	.5	50.77	.154	.853	.34 *
.838	3.0	3.2	.3	50.77	.157	.669	.27 *
.839	3.0	3.1	.1	50.77	.163	.431	.17 *
.840	2.9	2.9	.0	50.77	.171	.035	.01 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
.841	2.8	2.8	.0	50.77	.182	.076	.03 *
.842	2.7	2.7	.0	50.77	.196	.162	.07 *
.843	2.6	2.7	.0	50.77	.212	.162	.07 *
.844	2.6	2.7	.0	50.77	.231	.134	.08 *
.845	2.7	2.7	.0	50.77	.251	.101	.04 *
.846	2.8	2.8	.0	50.77	.271	.093	.04 *
.847	2.9	2.9	.0	50.77	.290	.076	.03 *
.848	3.0	3.0	.0	50.77	.308	.202	.08 *
.849	3.0	3.1	.1	50.77	.324	.408	.16 *
.850	3.0	3.3	.3	50.77	.336	.644	.25 *
.851	3.0	3.4	.4	50.77	.345	.836	.33 *
.852	3.0	3.6	.6	50.76	.349	.973	.39 *
.853	3.0	3.7	.7	50.76	.349	1.076	.42 *
.854	3.0	3.8	.8	50.76	.345	1.160	.45 *
.855	3.1	4.0	.9	50.76	.336	1.231	.47 *
.856	3.1	4.1	1.0	50.76	.324	1.290	.49 *
.857	3.1	4.1	1.0	50.76	.308	1.339	.51 *
.858	3.1	4.2	1.1	50.76	.290	1.380	.52 *
.859	3.1	4.3	1.2	50.75	.271	1.416	.53 *
.860	3.1	4.3	1.2	50.75	.251	1.446	.55 *
.861	3.1	4.4	1.3	50.75	.233	1.473	.56 *
.862	3.1	4.4	1.3	50.75	.216	1.496	.57 *
.863	3.1	4.4	1.3	50.75	.203	1.515	.58 *
.864	3.0	4.4	1.4	50.74	.194	1.530	.59 *
.865	3.0	4.4	1.4	50.74	.189	1.541	.60 *
.866	3.0	4.4	1.4	50.74	.139	1.545	.61 *
.867	2.9	4.4	1.4	50.74	.193	1.541	.61 *
.868	2.9	4.3	1.4	50.74	.201	1.528	.61 *
.869	2.9	4.3	1.4	50.74	.211	1.506	.61 *
.870	2.9	4.2	1.4	50.73	.221	1.473	.60 *
.871	2.9	4.1	1.3	50.73	.230	1.431	.59 *
.872	2.8	4.0	1.2	50.73	.236	1.379	.57 *
.873	2.9	3.9	1.1	50.73	.238	1.319	.54 *
.874	2.9	3.9	1.0	50.73	.234	1.252	.51 *
.875	2.9	3.8	.9	50.73	.223	1.179	.48 *
.876	2.9	3.7	.8	50.72	.206	1.103	.45 *
.877	2.9	3.6	.7	50.72	.182	1.025	.41 *
.878	3.0	3.5	.6	50.72	.152	.947	.38 *
.879	3.0	3.5	.5	50.72	.117	.869	.34 *
.880	3.0	3.4	.4	50.72	.078	.793	.31 *
.881	3.1	3.4	.3	50.72	.037	.719	.28 *
.882	3.1	3.3	.3	50.72	-.006	.648	.25 *
.883	3.1	3.3	.2	50.72	-.049	.581	.22 *
.884	3.1	3.3	.2	50.72	-.089	.519	.20 *
.885	3.1	3.3	.1	50.72	-.126	.465	.18 *
.886	3.1	3.2	.1	50.72	-.158	.424	.16 *
.887	3.1	3.2	.1	50.72	-.134	.401	.15 *
.888	3.1	3.2	.1	50.72	-.202	.404	.16 *
.889	3.1	3.2	.1	50.72	-.212	.435	.17 *
.890	3.1	3.2	.1	50.71	-.215	.492	.19 *
.891	3.1	3.3	.2	50.71	-.209	.554	.21 *
.892	3.1	3.3	.2	50.71	-.197	.633	.25 *
.893	3.1	3.4	.3	50.71	-.179	.721	.28 *
.894	3.0	3.4	.4	50.71	-.158	.809	.32 *
.895	3.0	3.5	.5	50.71	-.134	.893	.35 *
.896	3.0	3.6	.6	50.71	-.109	.969	.38 *
.897	3.0	3.7	.7	50.71	-.086	1.037	.41 *
.898	3.0	3.7	.7	50.71	-.066	1.096	.43 *
.899	3.0	3.8	.8	50.71	-.049	1.145	.45 *
.900	3.0	3.8	.9	50.71	-.035	1.186	.47 *
.901	3.0	3.9	.9	50.71	-.025	1.217	.48 *
.902	3.0	3.9	.9	50.71	-.017	1.239	.49 *
.903	3.0	3.9	1.0	50.70	-.011	1.252	.50 *
.904	3.0	3.9	1.0	50.70	-.006	1.258	.50 *
.905	3.0	3.9	1.0	50.70	-.000	1.255	.50 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
.906	3.0	3.9	.9	50.70	.006	1.244	.50 *
.907	2.9	3.9	.9	50.70	.014	1.226	.49 *
.908	2.9	3.8	.9	50.70	.025	1.202	.48 *
.909	2.9	3.8	.9	50.70	.038	1.171	.47 *
.910	2.9	3.7	.8	50.70	.053	1.134	.46 *
.911	2.9	3.6	.8	50.69	.070	1.092	.45 *
.912	2.9	3.6	.7	50.69	.088	1.044	.43 *
.913	2.9	3.5	.6	50.69	.108	.990	.41 *
.914	2.9	3.4	.6	50.69	.129	.930	.39 *
.915	2.8	3.3	.5	50.69	.150	.862	.36 *
.916	2.8	3.2	.4	50.69	.171	.787	.33 *
.917	2.8	3.2	.3	50.69	.191	.703	.29 *
.918	2.8	3.1	.2	50.69	.210	.609	.25 *
.919	2.9	3.0	.2	50.69	.227	.506	.21 *
.920	2.9	3.0	.1	50.69	.242	.393	.16 *
.921	2.9	2.9	.0	50.68	.255	.270	.11 *
.922	2.9	2.9	.0	50.68	.264	.135	.06 *
.923	2.9	2.9	.0	50.68	.270	.017	.01 *
.924	2.9	2.9	.0	50.68	.272	.068	.03 *
.925	3.0	3.0	.0	50.68	.270	.024	.01 *
.926	3.0	3.0	.0	50.68	.265	.037	.01 *
.927	3.1	3.1	.0	50.68	.257	.110	.04 *
.928	3.2	3.2	.0	50.68	.247	.236	.09 *
.929	3.2	3.3	.1	50.68	.235	.406	.15 *
.930	3.2	3.4	.2	50.68	.223	.575	.22 *
.931	3.1	3.4	.3	50.68	.210	.712	.27 *
.932	3.1	3.5	.4	50.68	.199	.811	.31 *
.933	3.1	3.6	.5	50.68	.190	.884	.34 *
.934	3.1	3.6	.5	50.68	.183	.940	.36 *
.935	3.1	3.7	.6	50.68	.179	.986	.38 *
.936	3.1	3.7	.6	50.68	.179	1.024	.39 *
.937	3.1	3.8	.7	50.67	.182	1.058	.40 *
.938	3.1	3.8	.7	50.67	.188	1.090	.42 *
.939	3.1	3.9	.7	50.67	.196	1.123	.43 *
.940	3.1	3.9	.8	50.67	.206	1.157	.44 *
.941	3.1	4.0	.8	50.67	.216	1.191	.45 *
.942	3.1	4.0	.9	50.67	.226	1.226	.46 *
.943	3.1	4.1	.9	50.67	.235	1.259	.47 *
.944	3.1	4.1	1.0	50.66	.243	1.290	.49 *
.945	3.1	4.1	1.0	50.66	.248	1.316	.50 *
.946	3.1	4.1	1.0	50.66	.250	1.338	.51 *
.947	3.1	4.1	1.1	50.66	.250	1.351	.52 *
.948	3.1	4.2	1.1	50.66	.248	1.362	.53 *
.949	3.0	4.1	1.1	50.66	.245	1.371	.53 *
.950	3.0	4.1	1.1	50.66	.241	1.376	.54 *
.951	3.0	4.1	1.2	50.65	.236	1.380	.55 *
.952	3.0	4.1	1.2	50.65	.232	1.384	.55 *
.953	2.9	4.1	1.2	50.65	.228	1.388	.56 *
.954	2.9	4.1	1.2	50.65	.225	1.393	.56 *
.955	2.9	4.1	1.2	50.65	.223	1.401	.56 *
.956	2.9	4.1	1.2	50.65	.222	1.409	.57 *
.957	2.9	4.2	1.2	50.64	.221	1.419	.57 *
.958	2.9	4.2	1.3	50.64	.220	1.429	.57 *
.959	2.9	4.2	1.3	50.64	.220	1.440	.58 *
.960	3.0	4.2	1.3	50.64	.219	1.449	.58 *
.961	3.0	4.3	1.3	50.64	.219	1.456	.57 *
.962	3.0	4.3	1.3	50.64	.219	1.462	.57 *
.963	3.0	4.3	1.3	50.63	.219	1.466	.57 *
.964	3.1	4.3	1.3	50.63	.220	1.467	.56 *
.965	3.1	4.3	1.3	50.63	.220	1.467	.56 *
.966	3.1	4.4	1.2	50.63	.221	1.466	.55 *
.967	3.1	4.4	1.2	50.63	.221	1.464	.55 *
.968	3.2	4.4	1.2	50.63	.220	1.462	.54 *
.969	3.2	4.4	1.2	50.62	.217	1.461	.54 *
.970	3.2	4.4	1.2	50.62	.213	1.461	.54 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
.971	3.2	4.4	1.2	50.62	.206	1.463	.53 *
.972	3.2	4.4	1.2	50.62	.196	1.466	.53 *
.973	3.3	4.5	1.2	50.62	.184	1.470	.53 *
.974	3.3	4.5	1.2	50.61	.170	1.474	.53 *
.975	3.3	4.5	1.2	50.61	.155	1.476	.53 *
.976	3.3	4.5	1.2	50.61	.139	1.476	.53 *
.977	3.3	4.5	1.2	50.61	.124	1.474	.53 *
.978	3.3	4.5	1.2	50.61	.110	1.468	.53 *
.979	3.2	4.4	1.2	50.61	.097	1.461	.53 *
.980	3.2	4.4	1.2	50.61	.387	1.450	.53 *
.981	3.2	4.4	1.2	50.60	.380	1.436	.53 *
.982	3.2	4.3	1.1	50.60	.074	1.422	.52 *
.983	3.2	4.3	1.1	50.60	.071	1.407	.52 *
.984	3.2	4.3	1.1	50.60	.070	1.392	.52 *
.985	3.2	4.3	1.1	50.60	.069	1.379	.51 *
.986	3.2	4.2	1.1	50.60	.068	1.366	.51 *
.987	3.2	4.2	1.0	50.59	.067	1.355	.50 *
.988	3.2	4.2	1.0	50.59	.065	1.344	.50 *
.989	3.2	4.2	1.0	50.59	.061	1.332	.50 *
.990	3.2	4.2	1.0	50.59	.056	1.319	.49 *
.991	3.2	4.1	1.0	50.59	.049	1.304	.49 *
.992	3.2	4.1	.9	50.59	.041	1.287	.48 *
.993	3.2	4.1	.9	50.59	.033	1.269	.47 *
.994	3.2	4.1	.9	50.59	.026	1.251	.46 *
.995	3.2	4.1	.9	50.58	.019	1.235	.45 *
.996	3.2	4.1	.8	50.58	.015	1.223	.45 *
.997	3.3	4.1	.8	50.58	.014	1.219	.44 *
.998	3.3	4.1	.3	50.58	.017	1.226	.44 *
.999	3.3	4.2	.9	50.58	.024	1.247	.45 *
1.000	3.3	4.2	.9	50.58	.037	1.282	.45 *
1.001	3.4	4.3	1.0	50.58	.055	1.333	.47 *
1.002	3.4	4.4	1.0	50.58	.078	1.398	.49 *
1.003	3.4	4.6	1.1	50.57	.105	1.473	.51 *
1.004	3.4	4.7	1.3	50.57	.137	1.555	.53 *
1.005	3.4	4.3	1.4	50.57	.171	1.640	.56 *
1.006	3.4	5.0	1.5	50.57	.208	1.723	.59 *
1.007	3.4	5.1	1.7	50.57	.246	1.800	.61 *
1.008	3.4	5.2	1.8	50.56	.284	1.870	.64 *
1.009	3.4	5.4	1.9	50.56	.320	1.931	.66 *
1.010	3.4	5.5	2.0	50.56	.355	1.982	.67 *
1.011	3.4	5.5	2.1	50.56	.387	2.024	.68 *
1.012	3.5	5.6	2.2	50.56	.417	2.057	.69 *
1.013	3.5	5.7	2.2	50.55	.443	2.082	.70 *
1.014	3.5	5.7	2.2	50.55	.464	2.098	.70 *
1.015	3.5	5.7	2.2	50.55	.480	2.104	.69 *
1.016	3.5	5.7	2.2	50.55	.485	2.095	.69 *
1.017	3.5	5.7	2.1	50.54	.477	2.061	.68 *
1.018	3.5	5.5	2.0	50.54	.447	1.991	.67 *
1.019	3.4	5.2	1.8	50.54	.389	1.370	.65 *
1.020	3.2	4.8	1.6	50.54	.295	1.680	.62 *
1.021	2.9	4.1	1.2	50.53	.159	1.407	.57 *
1.022	2.5	3.3	.8	50.53	-.019	1.040	.48 *
1.023	2.0	2.3	.3	50.53	-.232	.571	.33 *
1.024	1.3	1.3	.0	50.53	-.457	.010	.01 *
1.025	.1	.3	.2	50.53	-.659	.130	.89 *
1.026	.0	.0	.0	50.53	-.783	.010	.21 *
1.027	.0	.0	.0	50.53	-.757	.009	.21 *
1.028	3.9	4.0	.0	50.53	-.490	.121	.04 ?
1.029	3.2	3.7	.5	50.53	.119	.911	.34 *
1.030	3.7	3.4	4.7	50.53	1.172	3.242	.99 *
1.032	22.7	25.7	3.0	50.52	4.992	6.037	.31 ?
1.033	31.4	38.9	7.5	50.51	7.905	11.239	.41 *
1.034	44.2	55.2	11.0	50.49	11.509	16.112	.41 *
1.035	57.9	74.3	16.9	50.47	15.798	22.775	.44 *
1.036	75.3	97.2	21.9	50.43	20.711	29.451	.43 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
1.037	94.7	122.3	27.6	50.38	26.170	36.789	.41 *
1.038	116.9	149.4	32.5	50.31	32.057	44.322	.39 *
1.039	140.8	178.1	37.3	50.24	38.260	51.317	.37 *
1.040	166.1	207.3	41.8	50.15	44.659	58.421	.34 *
1.041	191.8	238.1	46.3	50.05	51.147	65.506	.32 *
1.042	217.3	268.5	51.2	49.93	57.632	72.687	.31 *
1.043	241.7	298.7	57.0	49.80	64.055	80.257	.30 *
1.044	264.1	328.5	64.4	49.65	70.358	88.505	.29 *
1.045	283.7	357.7	74.0	49.50	76.537	97.740	.29 *
1.046	300.0	386.3	86.3	49.32	82.552	108.046	.30 *
1.047	312.3	414.3	102.0	49.13	88.416	119.432	.32 *
1.048	320.4	441.6	121.1	48.92	94.114	131.531	.34 *
1.049	324.3	468.0	143.7	48.70	99.629	144.244	.37 *
1.050	329.7	493.4	163.8	48.45	105.074	155.346	.39 *
1.051	329.8	517.9	188.1	48.19	110.235	166.805	.42 *
1.052	328.3	541.1	212.7	47.92	115.131	177.434	.45 *
1.053	325.3	562.8	237.5	47.62	119.873	187.178	.48 *
1.054	321.6	582.8	261.3	47.32	124.291	195.859	.50 *
1.055	317.4	600.3	283.4	47.00	128.332	203.356	.53 *
1.056	312.9	616.7	303.8	46.66	131.996	209.806	.55 *
1.057	308.7	630.6	321.9	46.32	135.228	215.222	.57 *
1.058	304.6	642.6	338.0	45.97	137.962	219.766	.59 *
1.059	301.0	653.1	352.0	45.61	140.124	223.579	.61 *
1.060	297.8	662.4	364.7	45.25	141.602	226.905	.63 *
1.061	295.3	671.2	375.9	44.88	142.311	229.916	.64 *
1.062	293.4	680.0	386.6	44.51	142.168	232.849	.66 *
1.063	292.5	689.5	397.0	44.14	140.424	234.673	.67 *
1.064	292.2	699.6	407.4	43.76	138.285	237.824	.68 *
1.065	237.8	711.2	423.4	43.38	135.155	241.465	.70 *
1.066	288.4	724.4	436.1	43.01	131.072	245.460	.72 *
1.067	289.9	739.5	449.6	42.63	126.102	249.941	.73 *
1.068	292.4	756.3	463.9	42.25	120.333	254.892	.74 *
1.069	295.5	774.3	478.8	41.88	113.972	260.160	.75 *
1.070	299.2	793.2	494.0	41.51	107.187	265.641	.76 *
1.071	306.4	312.6	506.2	41.13	100.144	271.257	.76 *
1.072	310.7	332.3	521.6	40.76	93.000	276.890	.77 *
1.073	315.4	852.0	536.6	40.39	85.887	282.499	.78 *
1.074	320.1	871.7	551.5	40.02	78.894	288.064	.78 *
1.075	325.1	891.3	566.2	39.66	72.086	293.563	.79 *
1.076	330.2	910.8	580.5	39.29	65.506	299.001	.79 *
1.077	335.3	930.2	594.9	38.93	59.168	304.381	.80 *
1.078	340.1	949.4	609.3	38.56	53.090	309.682	.80 *
1.079	345.7	968.4	622.7	38.20	47.295	314.891	.80 *
1.080	350.6	986.9	636.2	37.34	41.807	319.905	.81 *
1.081	354.7	1004.3	649.6	37.48	36.636	324.622	.81 *
1.082	358.9	1020.4	661.5	37.11	31.820	328.938	.81 *
1.083	362.6	1034.6	672.0	36.75	27.386	332.732	.82 *
1.084	366.4	1046.2	679.8	36.39	23.404	335.849	.82 *
1.085	371.4	1055.0	683.6	36.03	19.870	338.252	.81 *
1.086	374.0	1060.9	686.9	35.68	16.771	339.314	.81 *
1.087	376.1	1063.5	687.4	35.32	14.097	340.528	.81 *
1.088	377.7	1062.8	685.0	34.97	11.798	340.370	.81 *
1.089	378.5	1058.9	680.4	34.61	9.861	339.372	.80 *
1.090	378.3	1052.1	673.3	34.26	8.246	337.589	.80 *
1.091	378.5	1042.6	664.1	33.92	6.907	335.082	.80 *
1.092	375.4	1030.7	655.4	33.58	5.806	331.915	.80 *
1.093	376.8	1016.9	640.1	33.24	4.894	328.224	.79 *
1.094	375.0	1001.6	626.6	32.91	4.097	324.096	.78 *
1.095	374.2	985.3	611.1	32.58	3.364	319.654	.78 *
1.096	373.7	968.4	594.7	32.25	2.643	315.003	.77 *
1.097	369.6	951.3	581.7	31.94	1.889	310.302	.77 *
1.098	367.5	934.4	566.9	31.62	1.070	305.590	.76 *
1.099	365.4	918.0	552.6	31.32	.151	300.967	.76 *
1.100	363.3	902.2	538.8	31.02	-.386	296.479	.75 *
1.101	361.2	887.1	525.9	30.72	-2.145	293.535	.75 *
1.102	359.4	872.7	513.3	30.43	-3.381	288.882	.74 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
1.103	359.3	358.8	499.6	30.14	-4.664	283.982	.74 *
1.104	357.4	845.3	487.9	29.86	-6.005	279.545	.73 *
1.105	355.4	832.0	476.5	29.59	-7.331	275.151	.73 *
1.106	353.3	818.7	465.4	29.32	-8.582	270.744	.73 *
1.107	350.7	805.3	454.7	29.06	-9.897	268.133	.72 *
1.108	347.8	791.6	443.9	28.80	-10.301	264.053	.72 *
1.109	344.4	777.6	433.3	28.55	-11.587	259.583	.72 *
1.110	341.0	763.4	422.4	28.30	-12.222	255.593	.71 *
1.111	337.3	748.9	411.6	28.06	-12.489	251.235	.71 *
1.112	333.0	734.3	401.4	27.82	-12.480	246.854	.71 *
1.113	328.3	719.8	391.5	27.58	-12.202	242.474	.71 *
1.114	323.3	705.4	382.1	27.35	-11.674	238.151	.71 *
1.115	318.1	691.3	373.2	27.13	-10.938	233.906	.71 *
1.116	312.8	677.5	364.7	26.91	-10.027	229.754	.71 *
1.117	307.3	664.1	356.8	26.69	-8.991	225.721	.71 *
1.118	301.4	651.0	349.6	26.47	-7.876	221.794	.71 *
1.119	293.0	638.2	345.2	26.25	-6.726	218.109	.72 *
1.120	289.3	625.4	336.1	26.04	-5.584	214.104	.72 *
1.121	282.6	612.6	330.1	25.83	-4.493	210.285	.72 *
1.122	275.8	599.7	323.9	25.63	-3.474	206.406	.73 *
1.123	268.8	586.7	317.8	25.43	-2.552	202.467	.74 *
1.124	261.6	573.5	311.8	25.23	-1.744	198.465	.74 *
1.125	254.3	560.1	305.3	25.03	-1.055	194.380	.75 *
1.126	251.0	546.8	295.8	24.84	-.498	190.098	.75 *
1.127	244.9	533.7	288.8	24.65	-.076	186.003	.75 *
1.128	239.6	521.0	281.4	24.46	.202	181.976	.75 *
1.129	234.5	508.9	274.4	24.28	.346	178.109	.75 *
1.130	229.7	497.5	267.8	24.10	.363	174.465	.76 *
1.131	225.8	486.9	261.1	23.93	.267	171.034	.75 *
1.132	222.2	477.2	255.0	23.75	.084	167.884	.76 *
1.133	219.6	468.4	248.8	23.59	-.156	164.959	.75 *
1.134	222.8	460.3	237.6	23.42	-.419	161.837	.73 *
1.135	218.7	452.9	234.2	23.26	-.667	159.489	.73 *
1.136	219.9	445.9	226.0	23.10	-.863	156.842	.72 *
1.137	217.7	439.2	221.4	22.94	-.982	154.565	.72 *
1.138	218.3	432.5	214.2	22.79	-1.001	152.033	.70 *
1.139	217.3	425.8	208.5	22.64	-.910	149.612	.70 *
1.140	207.0	419.0	212.0	22.49	-.707	148.105	.73 *
1.141	221.6	411.9	190.3	22.34	-.406	143.682	.66 *
1.142	220.1	404.7	184.6	22.20	-.026	141.032	.65 *
1.143	219.9	397.3	177.4	22.06	.405	138.087	.64 *
1.144	220.0	389.9	170.0	21.92	.861	135.031	.62 *
1.145	220.2	382.6	162.4	21.79	1.312	131.903	.61 *
1.146	220.1	375.3	155.2	21.65	1.735	128.809	.60 *
1.147	221.0	368.3	147.3	21.52	2.108	125.544	.58 *
1.148	221.3	361.5	140.2	21.39	2.419	122.443	.57 *
1.149	221.2	355.0	133.9	21.27	2.662	119.507	.55 *
1.150	216.9	348.9	132.0	21.15	2.840	117.711	.56 *
1.151	196.2	343.1	146.9	21.03	2.955	119.523	.63 *
1.152	206.6	337.6	130.9	20.90	3.019	114.949	.57 *
1.153	196.2	332.3	136.1	20.79	3.038	114.871	.60 *
1.154	213.4	327.3	114.0	20.67	3.028	108.382	.52 *
1.155	191.2	322.6	131.3	20.56	2.997	111.562	.60 *
1.156	211.0	317.9	107.0	20.44	2.958	104.400	.51 *
1.157	192.5	313.4	120.9	20.33	2.921	107.163	.58 *
1.158	208.0	309.1	101.0	20.22	2.894	100.794	.50 *
1.159	200.6	304.8	104.1	20.12	2.883	100.858	.52 *
1.160	199.6	300.5	100.9	20.02	2.892	99.047	.52 *
1.161	202.8	296.4	93.6	19.92	2.921	95.878	.49 *
1.162	201.0	292.3	91.3	19.82	2.967	94.317	.49 *
1.163	199.4	288.3	88.9	19.72	3.030	92.722	.48 *
1.164	197.9	284.4	86.5	19.62	3.101	91.135	.48 *
1.165	196.3	280.5	84.2	19.53	3.177	89.601	.48 *
1.166	194.7	276.7	82.0	19.44	3.251	88.075	.47 *
1.167	192.9	272.9	80.0	19.35	3.319	86.622	.47 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
1.168	191.2	269.2	78.0	19.26	3.377	85.173	.47 *
1.169	189.8	265.5	75.7	19.17	3.422	83.626	.46 *
1.170	188.3	261.9	73.6	19.08	3.456	82.173	.46 *
1.171	186.9	258.4	71.5	18.99	3.481	80.713	.45 *
1.172	185.8	255.0	69.2	18.91	3.497	79.164	.45 *
1.173	183.2	251.7	68.5	18.83	3.509	78.267	.45 *
1.174	182.8	248.6	65.8	18.75	3.519	76.604	.44 *
1.175	181.0	245.6	64.6	18.67	3.530	75.549	.44 *
1.176	180.3	242.7	62.4	18.59	3.543	74.128	.43 *
1.177	179.5	239.9	60.4	18.51	3.559	72.765	.43 *
1.178	173.1	237.2	59.1	18.43	3.578	71.709	.43 *
1.179	177.1	234.6	57.4	18.36	3.599	70.509	.42 *
1.180	176.1	231.9	55.9	18.28	3.622	69.335	.42 *
1.181	174.3	229.3	55.0	18.21	3.645	68.476	.42 *
1.182	173.4	226.7	53.3	18.14	3.671	67.225	.41 *
1.183	172.5	224.1	51.6	18.07	3.701	66.300	.41 *
1.184	171.8	221.6	49.8	18.00	3.737	64.719	.40 *
1.135	170.3	219.3	48.9	17.93	3.786	63.894	.40 *
1.136	169.4	217.1	47.7	17.86	3.849	62.885	.40 *
1.187	168.6	215.1	46.5	17.79	3.932	61.965	.39 *
1.188	168.3	213.3	45.0	17.73	4.034	60.908	.39 *
1.189	167.4	211.7	44.3	17.66	4.153	60.284	.38 *
1.190	166.6	210.3	43.7	17.60	4.285	59.722	.38 *
1.191	165.8	208.9	43.0	17.54	4.418	59.144	.38 *
1.192	165.5	207.4	41.9	17.47	4.541	58.291	.38 *
1.193	164.8	205.9	41.1	17.41	4.639	57.607	.37 *
1.194	164.3	204.2	39.9	17.35	4.697	56.690	.37 *
1.195	163.3	202.3	39.0	17.29	4.702	55.889	.37 *
1.196	150.9	200.3	49.4	17.22	4.647	60.398	.43 *
1.197	148.7	198.1	49.4	17.16	4.530	60.544	.44 *
1.198	147.9	195.9	48.0	17.09	4.358	59.509	.43 *
1.199	145.9	193.8	47.9	17.03	4.142	59.091	.44 *
1.201	144.8	189.9	45.1	16.90	3.656	57.131	.43 *
1.202	143.1	188.3	45.2	16.84	3.431	56.849	.43 *
1.203	137.8	186.8	49.0	16.78	3.244	58.312	.46 *
1.204	136.5	185.4	48.9	16.72	3.109	57.985	.46 *
1.205	135.2	184.0	48.9	16.66	3.032	57.726	.46 *
1.206	134.1	182.6	48.4	16.60	3.008	57.268	.46 *
1.207	133.1	180.9	47.8	16.54	3.022	56.700	.46 *
1.208	132.0	179.0	47.0	16.48	3.051	56.026	.46 *
1.209	130.7	176.8	46.1	16.42	3.069	55.228	.46 *
1.210	129.2	174.3	45.1	16.36	3.048	54.307	.46 *
1.211	127.5	171.5	44.0	16.30	2.965	53.314	.46 *
1.212	125.7	168.4	42.8	16.25	2.804	52.196	.45 *
1.213	123.7	165.2	41.5	16.19	2.564	51.063	.45 *
1.214	121.7	162.0	40.3	16.14	2.257	49.907	.45 *
1.215	119.7	158.9	39.2	16.09	1.907	48.831	.45 *
1.216	118.0	155.9	37.9	16.04	1.551	47.736	.45 *
1.217	116.1	153.3	37.2	15.99	1.233	46.913	.45 *
1.218	114.7	151.0	36.3	15.94	1.000	46.102	.44 *
1.219	113.3	149.2	35.9	15.89	.893	45.555	.45 *
1.220	112.2	147.7	35.5	15.85	.941	45.100	.45 *
1.221	111.2	146.5	35.2	15.80	1.163	44.773	.45 *
1.222	110.5	145.6	35.2	15.75	1.556	44.571	.45 *
1.223	109.8	144.9	35.1	15.71	2.098	44.422	.45 *
1.224	109.1	144.4	35.3	15.66	2.753	44.419	.45 *
1.225	108.5	143.9	35.4	15.61	3.469	44.369	.45 *
1.226	108.0	143.4	35.5	15.57	4.188	44.317	.45 *
1.227	107.5	143.0	35.5	15.52	4.850	44.229	.45 *
1.228	107.1	142.5	35.5	15.47	5.404	44.149	.45 *
1.229	106.6	142.1	35.5	15.42	5.807	44.065	.45 *
1.230	106.3	141.7	35.5	15.37	6.033	44.010	.46 *
1.231	106.1	141.5	35.4	15.32	6.073	43.918	.46 *
1.232	106.0	141.4	35.3	15.27	5.950	43.874	.46 *
1.233	105.8	141.4	35.5	15.22	5.668	43.733	.46 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
1.234	105.9	141.5	35.6	15.17	5.293	43.795	.46 *
1.235	105.9	141.6	35.8	15.12	4.858	43.924	.46 *
1.236	105.9	141.9	35.9	15.07	4.408	44.039	.46 *
1.237	106.2	142.0	35.9	15.02	3.986	44.030	.46 *
1.238	106.1	142.1	36.0	14.98	3.625	44.105	.46 *
1.239	106.4	142.0	35.7	14.93	3.348	43.953	.46 *
1.243	105.5	140.0	34.5	14.74	3.105	43.047	.45 *
1.244	104.9	139.1	34.3	14.69	3.192	42.782	.45 *
1.245	104.2	138.2	33.9	14.65	3.296	42.468	.45 *
1.246	103.6	137.2	33.6	14.60	3.394	42.117	.45 *
1.247	102.8	136.2	33.3	14.56	3.471	41.812	.45 *
1.248	102.1	135.2	33.0	14.51	3.514	41.498	.45 *
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1.252	100.0	131.3	31.3	14.33	3.297	39.974	.45 *
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1.296	101.2	104.2	2.9	13.05	3.525	12.187	.13 *
1.297	101.8	105.1	3.3	13.03	3.802	13.008	.14 *
1.298	102.4	106.2	3.8	13.02	4.123	13.973	.15 *
1.299	103.2	107.6	4.4	13.00	4.474	15.103	.16 *
1.300	104.0	109.1	5.1	12.98	4.838	16.304	.17 *
1.301	104.9	110.8	5.9	12.96	5.190	17.559	.18 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
1.302	105.9	112.6	6.7	12.94	5.511	18.918	.20 *
1.303	106.8	114.5	7.7	12.91	5.776	20.317	.21 *
1.304	107.7	116.4	3.3	12.89	5.966	21.779	.22 *
1.305	108.4	118.3	9.9	12.86	6.067	23.222	.24 *
1.306	109.1	120.1	11.1	12.83	6.071	24.622	.25 *
1.307	110.1	121.3	11.8	12.80	5.977	25.494	.26 *
1.308	110.5	123.4	12.9	12.77	5.793	26.779	.27 *
1.309	110.5	124.7	14.2	12.73	5.532	28.084	.28 *
1.310	111.0	125.9	14.3	12.70	5.213	28.789	.29 *
1.311	110.8	126.8	15.9	12.67	4.861	29.846	.30 *
1.312	110.3	127.5	17.2	12.63	4.501	30.923	.31 *
1.313	110.3	127.9	17.6	12.60	4.157	31.339	.31 *
1.314	109.9	128.1	18.3	12.56	3.851	31.855	.32 *
1.315	109.3	128.2	18.9	12.52	3.599	32.329	.33 *
1.316	108.3	128.1	19.7	12.49	3.411	32.932	.34 *
1.317	107.6	127.3	20.2	12.45	3.291	33.221	.34 *
1.318	101.6	127.4	25.9	12.42	3.235	36.734	.40 *
1.319	100.3	127.0	26.7	12.38	3.234	37.115	.41 *
1.320	99.2	126.5	27.3	12.34	3.276	37.349	.42 *
1.321	98.6	125.9	27.4	12.29	3.345	37.301	.42 *
1.322	97.8	125.4	27.6	12.25	3.425	37.342	.42 *
1.323	97.2	124.9	27.6	12.21	3.502	37.248	.43 *
1.324	96.7	124.3	27.6	12.17	3.563	37.165	.43 *
1.325	95.9	123.9	28.0	12.13	3.602	37.247	.43 *
1.326	95.5	123.4	27.9	12.09	3.615	37.148	.43 *
1.327	95.1	123.0	27.9	12.05	3.603	37.056	.43 *
1.328	94.7	122.6	27.9	12.01	3.571	36.963	.43 *
1.329	94.4	122.2	27.8	11.97	3.526	36.861	.43 *
1.330	94.1	121.8	27.7	11.93	3.475	36.742	.43 *
1.331	93.8	121.5	27.6	11.89	3.426	36.657	.44 *
1.332	93.7	121.1	27.5	11.85	3.387	36.499	.43 *
1.333	93.9	120.8	26.9	11.81	3.362	36.128	.43 *
1.334	93.7	120.4	26.7	11.77	3.352	36.003	.43 *
1.335	93.7	120.1	26.4	11.73	3.357	35.754	.43 *
1.336	93.8	119.7	26.0	11.69	3.375	35.463	.42 *
1.337	93.3	119.4	26.0	11.65	3.400	35.449	.42 *
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1.342	94.0	117.7	23.6	11.46	3.464	33.843	.40 *
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1.345	94.5	116.6	22.1	11.35	3.360	32.755	.39 *
1.346	95.0	116.2	21.2	11.31	3.308	32.125	.38 *
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1.348	94.6	115.3	20.3	11.24	3.198	31.724	.38 *
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1.351	94.8	113.3	19.0	11.14	3.062	30.319	.36 *
1.352	94.8	113.2	18.4	11.11	3.030	29.850	.35 *
1.353	94.8	112.6	17.8	11.07	3.005	29.377	.35 *
1.354	94.8	112.0	17.3	11.04	2.986	28.893	.34 *
1.355	94.3	111.4	17.2	11.01	2.971	28.738	.34 *
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1.360	93.4	108.4	15.0	10.85	2.921	26.736	.32 *
1.361	92.8	107.9	15.1	10.33	2.911	26.700	.32 *
1.362	92.8	107.3	14.5	10.30	2.900	26.157	.32 *
1.363	92.5	106.7	14.2	10.77	2.890	25.382	.32 *
1.364	92.2	106.2	14.0	10.74	2.880	25.640	.31 *
1.365	91.8	105.7	13.3	10.71	2.871	25.432	.31 *
1.366	91.3	105.1	13.3	10.68	2.864	25.367	.31 *

TIME (ms)	PRESSURE (MPa)	STRESS (MPa)	THRUST (MPa)	LENGTH (mm)	Up (m/sec)	BURNING RATE (m/sec)	Ug/Cg
1.367	90.8	104.6	13.8	10.65	2.860	25.270	.31 *
1.368	89.7	104.1	14.4	10.62	2.858	25.698	.32 *
1.372	88.2	102.4	14.2	10.51	2.882	25.295	.32 *
1.373	87.1	102.0	15.0	10.48	2.896	25.835	.34 *
1.374	85.9	101.7	15.8	10.45	2.913	26.355	.35 *
1.375	85.0	101.4	16.4	10.42	2.931	26.757	.36 *
1.376	85.3	101.1	15.8	10.39	2.951	26.306	.35 *
1.377	84.3	100.9	16.6	10.37	2.970	26.810	.36 *
1.378	83.2	100.7	17.5	10.34	2.987	27.359	.37 *
1.379	82.1	100.5	18.4	10.31	3.000	27.880	.38 *
1.380	81.1	100.3	19.2	10.27	3.002	28.351	.40 *
1.381	79.8	100.0	20.2	10.24	2.990	28.909	.41 *
1.382	78.4	99.7	21.3	10.21	2.957	29.464	.43 *
1.383	76.8	99.3	22.4	10.18	2.896	29.965	.44 *
1.384	75.4	98.7	23.4	10.15	2.799	30.332	.46 *
1.385	73.8	98.0	24.2	10.11	2.661	30.599	.47 *
1.386	72.1	97.1	25.0	10.08	2.481	30.748	.48 *
1.387	70.4	95.9	25.6	10.05	2.262	30.773	.50 *
1.388	68.5	94.6	26.1	10.01	2.015	30.692	.51 *
1.389	66.8	93.1	26.3	9.98	1.762	30.468	.52 *
1.390	65.1	91.5	26.4	9.95	1.534	30.170	.53 *
1.391	63.4	89.9	26.5	9.92	1.371	29.856	.54 *
1.392	62.0	88.6	26.5	9.89	1.323	29.578	.54 *
1.393	60.9	87.6	26.8	9.85	1.442	29.457	.55 *
1.394	60.3	87.4	27.1	9.82	1.780	29.516	.56 *
1.395	60.3	88.1	27.8	9.79	2.381	29.899	.56 *
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1.399	68.7	105.0	36.4	9.65	7.666	36.582	.60 *
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